This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

KF 8304

NEDL TRANSFER
HN 6IPC F

DESCRIPTIVE LIST
OF
ELEMENTARY EXERCISES IN PHYSICS

E. Greenwood,
May 5, 1927.

Helen E. Greenwood

DESCRIPTIVE LIST
OF
ELEMENTARY EXERCISES IN PHYSICS

CORRESPONDING TO THE

REQUIREMENT IN ELEMENTARY EXPERIMENTAL PHYSICS
FOR ADMISSION TO HARVARD COLLEGE AND
THE LAWRENCE SCIENTIFIC SCHOOL

BY

EDWIN H. HALL

PROFESSOR OF PHYSICS IN HARVARD UNIVERSITY

CAMBRIDGE
Published by Harvard University
1897

KF 8304

HARVARD
UNIVERSITY
LIBRARY
0~~46~~*172

INTRODUCTION.

The purpose of this publication, entitled a *Descriptive List of Elementary Exercises in Physics*, is explained by the following statement, recently adopted as a definition of the requirement in elementary experimental physics for admission to Harvard College and the Lawrence Scientific School:

"A course of study dealing with the leading elementary facts and principles of physics, with quantitative laboratory work by the pupil.

The instruction given in this course should include qualitative lecture-room experiments, and should direct especial attention to the illustrations and applications of physical laws to be found in everyday life. The candidate will be required to pass a written examination, the main object of which will be to determine how much he has profited by such instruction. This examination may include numerical problems. It will contain more questions than any one candidate is expected to answer, in order to make allowance for a considerable diversity of instruction in different schools.

The pupil's laboratory work should give practice in the observation and explanation of physical phenomena, some familiarity with methods of measurement and some training of the hand and the eye in the direction of precision and skill. It should also be regarded as a means of fixing in the mind of the pupil a considerable variety of facts and principles. The candidate will be required to pass a laboratory examination, the main object of which will be to determine how much he has profited by such a laboratory course.

The candidate must name as the basis for his laboratory examination at least thirty-five exercises selected from a list of about sixty described in a publication issued by the University under the title, "Descriptive List of Elementary Exercises in Physics." In this list the divisions are mechanics (including hydrostatics), light, heat, sound, and electricity (with magnetism). At least ten of the exercises selected must be in mechanics. Any one of the four other divisions may be omitted altogether, but each of the three remaining divisions must be represented by at least three exercises.

The candidate will be required to present a note-book in which he has recorded the steps and the results of his laboratory exercises, and this note-book must bear the endorsement of his teacher, certifying that the notes are a true record of the pupil's work. It should contain an index of the exercises which it describes. These exercises need not be the same as those upon which the candidate presents himself for the laboratory examination, but should be equivalent to the latter in amount and grade of quantitative work.

The note-book is required as proof that the candidate has formed the habit of keeping a full and intelligent record of laboratory work through an extended course of experiments, and that his work has been of such a character as to raise a presumption in favor of his preparation for the examination. But much greater weight will be given to the laboratory examination than to the note-book in determining the candidate's attainments in physics. Experience has shown that pupils can make the original record of their observations entirely presentable, so that copying will be unnecessary, and they should in general be required to do so.

This course, if taken in the last year of the candidate's preparation, is expected to occupy in laboratory work, recitations, and lectures, five of the ordinary school periods, about fifty minutes in length, per week for the whole year. With few exceptions exercises like those in the Descriptive List already mentioned can be performed in a single school period, but for satisfactory results it will often be necessary to repeat an exercise. Two periods per week for the year should be sufficient for the laboratory work proper. If the course is begun much earlier than the last year of the candidate's preparation, as it may well be, it will require more time."

The requirement described in the preceding quotation differs from the corresponding requirement that has existed at Harvard in several important particulars. The new requirement, as compared with the old one,

(1) includes more qualitative and descriptive work,

(2) includes less laboratory work on the part of the pupil,

(3) puts the note-book requirement on a somewhat different basis,

(4) in general, removes from the work of the pupil and of the teacher restrictions which no longer appear necessary.

A form of certificate, similar to the following, will be printed by the College on slips suitable for placing in the note-books, and these slips will be furnished on application to the College Secretary: —

This note-book contains a true record of the laboratory work of

....

written by himself. The work was done under my supervision.

Signature of teacher..

In determining both the substance and the form of the laboratory record the student should ask, not so much what kind of a record the Harvard examiners will require, but rather, what kind of a record will be most serviceable for himself in reviewing. He should keep the note-book in such a way that it will readily recall to his mind the purposes, methods, and results of the several exercises performed. The record should be well-ordered, plainly legible, and concise. Simple drawings are the briefest and best descriptions of most apparatus. Long repetitions of directions or descriptions given elsewhere should be avoided.

The division of the work into a First Part and a Second Part is intended to facilitate and encourage beginning the study of physics very early in the school course. Most of the exercises in the First Part have proved to be quite within the power of boys fourteen or fifteen years old. The cost of apparatus for these exercises is very small, as the estimate on the following page will show.

A list of apparatus for the whole course has been made with much care and is given in the Appendix. Well-known manufacturers* in Boston and elsewhere will undertake to furnish everything at a reasonable price and nearly everything at very short notice.

Many teachers and manufacturers, some of whom are mentioned by name in the following pages, have contributed to the form of the course or the form of the apparatus, as these now appear. A few acknowledgments previously made it has seemed unnecessary to repeat.

* The Franklin Educational Company, Harcourt Street, Boston, Mass.
The Knott Company, 14 Ashburton Place, Boston, Mass.
The Ziegler Company, 141 Franklin Street, Boston, Mass.
The Ritchie Company, Brookline, Mass.
The Olmsted Scientific Company, 215 Wabash Avenue, Chicago.

NOTE.

The following estimates of cost for apparatus and materials are only approximate. It is hardly possible to make an accurate estimate, as prices will vary from time to time and different dealers may have somewhat different grades of apparatus. The cheapest is not necessarily the best to buy.

FOR ALL EXERCISES OF THE FIRST PART.

Apparatus for a laboratory section of one	$6.00
Apparatus for a laboratory section of twelve	72.00
Tables for a laboratory section of twelve	50.00

These tables serve also for the Second Part.

FOR ALL EXERCISES OF THE SECOND PART.

Apparatus for a laboratory section of one	$90.00
Apparatus for a laboratory section of twelve	750.00

FOR THIRTY-FIVE EXERCISES OF AVERAGE EXPENSE.

Apparatus for a laboratory section of twelve	$475.00
Tables for a laboratory section of twelve	50.00

CONTENTS.

FIRST PART.

Preliminary Exercises.

[Recommended but not to be counted.]

PAGE
A. Measurement of a Straight Line 1
B. Lines of the Right Triangle and the Circle 2
C. Area of an Oblique Parallelogram 2
D. Volume of a Rectangular Body by Displacement of Water 3

MECHANICS AND HYDROSTATICS.

EXER.
1. Weight of Unit Volume of a Substance 4
2. Lifting Effect of Water upon a Body Entirely Immersed in It . . . 5
3. Specific Gravity of a Solid Body that will Sink in Water 5
4. Specific Gravity of a Block of Wood by Use of a Sinker 6
5. Weight of Water Displaced by a Floating Body 7
6. Specific Gravity by Flotation Method 8
7. Specific Gravity of a Liquid: Two Methods 9
8. The Straight Lever: First Class 10
9. Centre of Gravity and Weight of a Lever 11
10. Levers of the Second and Third Classes 12
11. Force Exerted at the Fulcrum of a Lever 13
12. Errors of a Spring-Balance 13
13. Parallelogram of Forces 15
14. Friction between Solid Bodies (on a level) 18
15. Coefficient of Friction (by sliding on incline) 19

LIGHT.

16. Use of Rumford Photometer 20
17. Images in a Plane Mirror 21
18. Images formed by a Convex Cylindrical Mirror 24
19. Images formed by a Concave Cylindrical Mirror 26
20. Index of Refraction of Glass 27
21. Index of Refraction of Water 28
22. Focal Length of a Converging Lens 29

EXER. PAGE
23. Conjugate Foci of a Lens 31
24. Shape and Size of a Real Image formed by a Lens 32
25. Virtual Image formed by a Lens 34

SECOND PART.

MECHANICS.

26. Breaking-Strength of a Wire 35
27. Comparison of Wires in Breaking Tests 36
28. Elasticity: Stretching 38
29. Elasticity: Bending; Effect of Varying Load 39
30. Elasticity: Bending; Effect of Varying Dimensions 41
31. Elasticity: Twisting 41
32. Specific Gravity of a Liquid by Balancing Columns 43
33. Compressibility of Air: Boyle's Law 45
34. Density of Air 46
35. Four Forces at Right Angles in One Plane 47
36. Comparison of Masses by Acceleration-Test 48
37. Action and Reaction: Elastic Collision 51
38. Elastic Collision Continued; Inelastic Collision 53

HEAT.

39. Testing a Mercury Thermometer 54
40. Linear Expansion of a Solid 56
41. Increase of Pressure of a Gas Heated at Constant Volume 58
42. Increase of Volume of a Gas Heated at Constant Pressure 61
43. Specific Heat of a Solid 61
44. Latent Heat of Melting 62
45. Determination of the Dew-Point 63
46. Latent Heat of Vaporization 64

SOUND.

47. Velocity of Sound in Open Air 66
48. Wave-Length of Sound 66
49. Number of Vibrations of a Tuning-Fork 67

ELECTRICITY AND MAGNETISM.

50. Lines of Force near a Bar Magnet 68
51. Study of a Single-Fluid Galvanic Cell 69
52. Study of a Two-Fluid Galvanic Cell 71
53. Lines of Force about a Galvanoscope 72
54. Resistance of Wires by Substitution: Various Lengths 74

EXER. PAGE
55. Resistance of Wires by Substitution: Cross-section and Multiple Arc . 75
56. Resistance by Wheatstone's Bridge: Specific Resistance of Copper . 77
57. Temperature-Coefficient of Resistance in Copper 78
58. Battery Resistance 79
59. Putting together the Parts of a Telegraph Key and Sounder 80
60. Putting together the Parts of a Small Motor 81
61. Putting together the Parts of a Small Dynamo 81

APPENDIX.

LIST OF APPARATUS FOR THE EXERCISES OF THE FIRST PART 82
LIST OF APPARATUS FOR THE EXERCISES OF THE SECOND PART . . . 84

DESCRIPTIVE LIST
OF
ELEMENTARY EXERCISES IN PHYSICS.

INTENDED FOR USE IN PREPARING STUDENTS FOR HARVARD COLLEGE AND THE LAWRENCE SCIENTIFIC SCHOOL.

FIRST PART.

Preliminary Exercises: A, B, C, and D.

[Recommended but not to be counted.]

EXERCISE A.

MEASUREMENT OF A STRAIGHT LINE.

Apparatus: A short measuring-stick (No. 1)* and a meter-rod (No. 2).

To each pupil is given a measuring-stick about one-fourth as long as the distance to be measured, e. g., the distance is between two parallel marks on the table. We will suppose that these sticks are made by sawing a meter-rod, graduated by millimeters, into ten equal parts. The saw-cut will usually leave the divisions at the very ends of the sticks imperfect, and these divisions should not be used in the measurements.

Let each pupil measure his distance at least twice, carefully, with his measuring-stick laid flat upon the table, the marks upon the stick being thus *horizontal*, and let him write upon the blackboard the results of his two measurements.

Then let each pupil measure his distance twice again, this time placing his measuring-stick upon its edge, so that the marks upon it will be vertical, making a light, fine mark upon the table with a sharp pencil to *set* the stick by, whenever it is moved forward a length. These new measurements are also to be placed upon the blackboard under the first ones.

Finally let each pupil measure his whole distance at once with his meter-rod and write this last measurement with the others.

---

* Any piece of apparatus to be used in the Exercises will usually be referred to by the number it bears in the list of apparatus given at the end of the book.

EXERCISE B.

THE LINES OF THE RIGHT TRIANGLE AND THE CIRCLE.

Apparatus: A 30-cm. measuring-stick (No. 3). A sheet of paper upon which is drawn carefully a right triangle no side of which is less than 10 cm. long. (No two pupils should use exactly similar triangles.) A cylinder of wood 4 or 5 cm. in diameter (No. 4). A narrow straight-edged strip of paper.

Part I. MEASUREMENT OF THE SIDES OF A RIGHT TRIANGLE.—Let each pupil measure very carefully all the sides of this triangle, not being content to read to the nearest 0.1 cm., but striving to note and measure 0.05 cm. distances, if he can do so without hurting his eyes.

After the measurements are made, square the length of each side and compare the greatest square with the sum of the other two squares. The conclusion drawn from this comparison must not be extended to triangles which are not right-angled.

Part II. MEASUREMENT OF THE CIRCUMFERENCE AND DIAMETER OF A CIRCLE.—Measure carefully the diameter of one end of the cylinder. Then wrap the strip of paper around the curved surface of the cylinder at the same end, and mark upon the edge of the strip the point where the second winding of the paper begins to overlap the first. Then unfold the paper and measure upon it that distance which extended once around the cylinder. Then divide this distance, which of course is equal to the circumference of the circle, by the length of the diameter. The ratio thus obtained is one which it is important to know, although we shall not have much occasion to use it in this book. Mathematicians, physicists, and engineers use it so much that they have a particular sign, π, to denote it.

This sign is a Greek letter and is called *pē* by students of Greek, but when used as just described it is often called *pī* to distinguish it from *p*.

EXERCISE C.

AREA OF AN OBLIQUE PARALLELOGRAM.

Apparatus: The 30-cm. measuring-stick (No. 3). An oblique parallelogram of paper about 20 cm. long and 10 cm. wide. (One of the straight-edged rulers (No. 27) may prove useful in this Exercise.)

Draw upon the paper figure a line like *c* in Fig. 1, taking care to make a right angle with the top line and the bottom line, and then cut or tear the paper along the line *c*. Take the small piece thus removed and join it to the larger piece, in such a way as to make a figure that you know how to measure. Measure the length and width of the figure thus formed and calculate the extent of its surface.

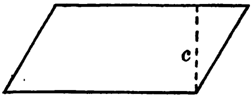

FIG. 1.

Then put the two pieces together as they were at first and ask yourself whether you could not, if another oblique parallelogram were given you, find the extent of its surface without cutting it.

EXERCISE D.

VOLUME OF A RECTANGULAR BODY BY DISPLACEMENT OF WATER.

Apparatus: A brass can (No. 5) called *C* in Fig. 2. A small catch-bucket (No. 6) called *p* in Fig. 2. A spring-balance (No. 7). A rectangular block of wood (No. 8) so loaded as to sink in water.

Closing the overflow tube *t* of the can *C*, pour water into *C* until it is filled nearly to the brim. Then open the tube and let all the water flow out that will do so, catching it in the small can *p*. The large can should rest steadily upon the table, but the small one is better held in the hand when the flow begins, otherwise some water may be spilled. The flow should stop rather suddenly at last, with little or no drip.

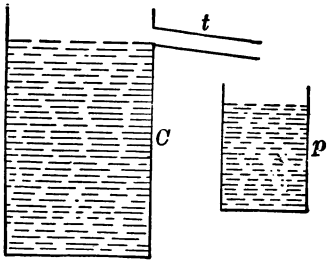

FIG. 2.

Throw away all the water thus caught in *p* and then weigh *p* on the spring-balance to the nearest gram or the nearest twentieth of an ounce, according to the graduation of the balance.* Then, closing the tube *t* as before, lower into the can *C* the wooden block until it rests upon the bottom. Then, or sooner if the can *C* seems likely to be overflowed, open the tube *t*, and as before catch the water that runs out in the small can *p*. The water, Fig. 3, now stands just as high in *C* as it did just before the block was put into it. The block has crowded out into the can *p* just its own bulk of water. If, then, we can find the volume of water that the block drove over into *p*, we shall have the volume of the block itself.

---

* Ordinary small spring-balances now in the market are often marked off in half-ounce divisions, which are about $\frac{1}{8}$ inch long. The pupil will learn to *estimate* the position of the pointer when it falls between two lines, so as to read to about $\frac{1}{20}$ of an ounce.

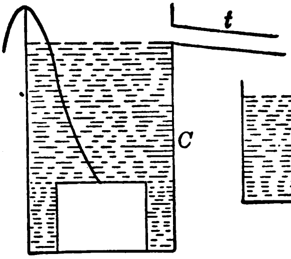

FIG. 3.

Weigh *p* and the water it contains.

Weight of small can and water = . . .
“ “ “ “ empty = . . .
“ “ water alone = . . .

If the weight as thus found is in grams, it is equal to the number of cubic centimeters in the block. If the weight as thus found is in ounces, we must multiply the number of ounces by 28.3 in order to find the number of cubic centimeters in the block.

Now measure carefully the length, width, and thickness of the block and calculate the number of cubic centimeters it contains from these measurements.

(Experiments for finding the volumes of irregular bodies by the water method may well be postponed till the next Exercise, which would otherwise be a very brief one. Potatoes, stones, lumps of coal, etc., of suitable size may be used for these further experiments.

MECHANICS AND HYDROSTATICS.

EXERCISE 1.

WEIGHT OF UNIT VOLUME OF A SUBSTANCE.

Apparatus: A block of wood (No. 9). A spring-balance (No. 7). A measuring-stick (No. 3). Thread for suspending the block.

Find the weight of the block in grams and also in ounces.

Measure the length of each of the four edges which are parallel to the grain of the wood, take the average of these measurements and call it the *length* of the block.

Measure the length of each of the four long edges which are crosswise to the grain of the wood, and call the average of these four measurements the *width* of the block.

Measure the length of each of the four short edges and call the average of these four measurements the *thickness* of the block.

The weight in ounces is to be turned into pounds.

From the length, width, and thickness in centimeters the length, width, and thickness in *feet* may be found by the rule that 1 ft. = 30.5 cm., but it is shorter to find the volume in feet from the volumes in cubic centimeters by the rule that 1 cu. ft. = 28300 cu. cm.

Calculate, 1st, how many grams, or what part of a gram, 1 cu. cm. of the block weighs; 2d, how many pounds, or what part of a pound, 1 cu. ft. of such wood weighs.

EXERCISE 2.

LIFTING EFFECT OF WATER UPON A BODY ENTIRELY IMMERSED IN IT.

Apparatus: Overflow-can (No. 5). Catch-bucket (No. 6). Spring-balance (No. 7). Loaded block (No. 8). Thread.

Fill the can and let it overflow and drip as in Exercise D. Catch this overflow in the small bucket and throw it away. Then weigh the empty bucket in grams.

Weigh the block in grams before immersing it in the water.

Lower the block, still suspended from the balance, into the overflow-can till it is entirely covered, catching the overflow and saving it.

Weigh the block in the water, the balance being entirely above the water.

Weigh the bucket with the overflowed water.

Subtract the (apparent) weight of the block in water from its weight in air, and call the difference the *loss of weight of the block in water*, or the *buoyant force exerted upon the block by the water.*

Find weight of the water in the small bucket, and compare this with the loss of weight of the block in water.

If there is time, make a similar experiment with other bodies.

The law illustrated in this Exercise is called from its discoverer the *law*, or *principle*, of *Archimedes.* (See any encyclopaedia for an account of Archimedes.)

EXERCISE 3.

SPECIFIC GRAVITY OF A SOLID BODY THAT WILL SINK IN WATER.

Apparatus: The spring-balance (No. 7). The gallon jar (No. 10) nearly filled with water. A lump of sulphur (No. 11). Thread.

Weigh the sulphur out of water; then in water.

We know from Exercise 2 that a body immersed in water loses in apparent weight an amount equal to the weight of the water whose place it has taken. It is easy, therefore, to get from the two weighings just made the ratio which we have undertaken to find in this Exercise.

If time permits, find in this Exercise, by the same method that is used for the sulphur, the specific gravity of other solids that will sink in water — such as glass, coal, etc.

EXERCISE 4.

SPECIFIC GRAVITY OF A BLOCK OF WOOD BY USE OF A SINKER.

Apparatus: A rectangular block of wood (No. 9). The spring-balance (No. 7). The gallon jar (No. 10) nearly filled with water. A lead sinker (No. 12). Thread.

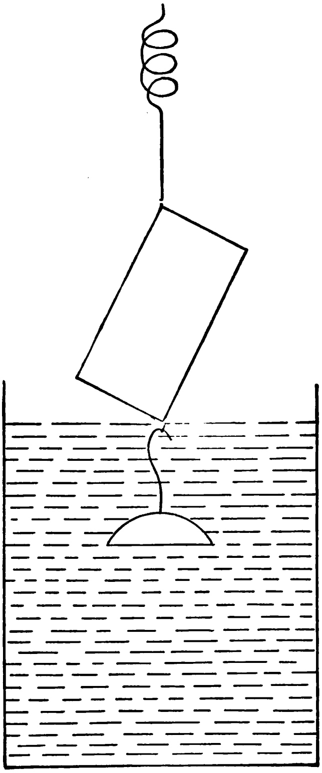

FIG. 4.

We have to find two quantities, by experiment: 1st, the *weight of the body;* 2d, the *lifting effect of water upon it when immersed.*

Weigh the wood in air and record its weight.

Now put the block into water. You see that it floats. To make it stay under water you must *hold it down.* Try this, putting your fingers on the block. In this case, you see, the lifting effect of the water, when the block is wholly beneath its surface, is greater than the weight of the block. We must find out how much it is.

We shall use the lead sinker to hold the block under water, and we need to know the weight of the sinker alone under water. Weigh it in this position and record the weight.

Now suspend the block from the balance* and the lead sinker from the thread under the block, and consider how much the two, block and sinker, would weigh in the position shown in Fig. 4, the block out of water and the sinker in water. You can tell this from the weighings already made. Write it down.

Wt. of block in air + *Wt. of sinker in water* = ... + ...

Now lower the block and sinker till both are covered by the water, and weigh the two together in this position and record:

Wt. of block and sinker together in water = ...

Just before the *block* entered the water, the sinker being already in, the weight was . . . . Just as soon as the block also was covered the weight was only . . . . The difference is the *lifting effect of the water upon the block.* We have now all that we need for calculating the specific gravity of the block by means of the formula,

$$Sp.\ grav. = \frac{Wt.\ of\ block}{Lifting\ effect\ of\ water\ upon\ block\ immersed}.$$

EXERCISE 5.

WEIGHT OF WATER DISPLACED BY A FLOATING BODY.

Apparatus: The same as in Exercise 2, with the exception of the sinking body, which is here replaced by one that floats (No. 4).

Weigh the cylinder, in grams, in air. Find, in grams, the weight of water which it displaces from the overflow pan. Compare these two weights.

It will be well to repeat the overflow operation carefully a number of times.

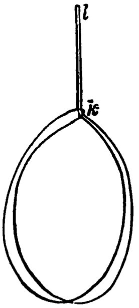

FIG. 5.

---

* The success of a difficult experiment like this depends greatly upon the care with which the details of the work are thought out by the teacher. The following method of attaching the block to the balance is recommended: Take a thread two feet long and tie the ends together. Then make of it a slip-noose by passing one end, *l* (Fig. 5), through the other end, *k*. The block may then be place in the noose and the loop *l* slipped on to the hook of the balance, but to prevent slipping when the lead weight is to be suspended from the loop below the block it is well to pass the loop *l twice* through at *k*.

EXERCISE 6.

SPECIFIC GRAVITY BY FLOATING METHOD.

Apparatus: The gallon jar (No. 10) nearly filled with water. A slender wooden cylinder (No. 13). A support for holding this cylinder upright in water (No. 14). A measuring-stick (No. 3).

If a cylinder floated upright with its top just level with the top of the water, we should at once know its specific gravity to be 1. If it floated just half in and half out of water, we should know its specific gravity to be 0.5. The cylinder that we have to use will not float all in water or exactly half in water, but if we float it, and find the length of the part then in the water, we shall, by comparing this with the length of the whole cylinder, find some way of ascertaining the specific gravity of the cylinder.

Measure the length of the whole cylinder.

Float the cylinder in the jar (Fig. 6), keeping it upright by means of the holder, which is attached to the side of the jar. Joggle the cylinder to make sure that it is free to take its proper position. After each joggling it should come to rest at the same depth as before. The rings of the holder must not *grip* the cylinder at all. When sure that the cylinder floats as it should, measure the length of the submerged part, from the bottom of the cylinder up to the *flat* surface of the water.

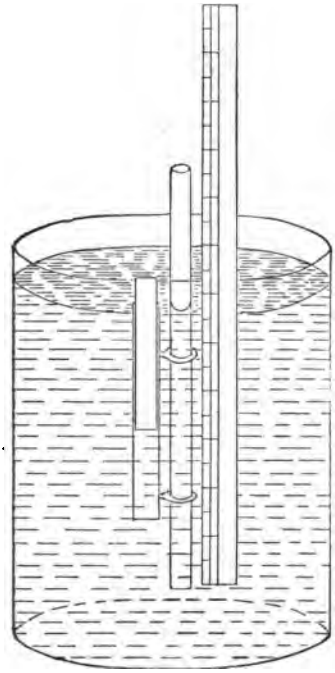

FIG. 6.

To find the specific gravity from the two measurements now made, begin by recalling the fact (see Exercise 5) that the water displaced by the floating cylinder weighs just as much as the cylinder itself.

How many times is the length of the submerged part of the cylinder contained in the whole length?

How many times the weight of the cylinder would be the weight of a like cylinder of water?

How great, then, do you find the specific gravity of the wooden cylinder to be?

EXERCISE 7.

SPECIFIC GRAVITY OF A LIQUID: TWO METHODS.

Apparatus: The gallon jar (No. 10) nearly filled with water, and the smaller jar (No. 15) nearly filled with a solution of sulphate of copper.* The small glass bottle (No. 16). The spring-balance (No. 7). Thread.

First Method.

Weigh the bottle empty. Dip the bottle into the jar of sulphate of copper and let it fill with the liquid. Holding the bottle over the jar, put the stopper in place, thus crowding out the excess of liquid, then wipe the outside of the bottle and weigh it carefully with its contents.

Pour the sulphate of copper back into its jar, then fill the bottle with water, just as it was before filled with the other liquid, and again weigh the bottle and its contents.

From the three weighings now made the specific gravity of sulphate of copper can easily be found.

Second Method.

We found in Exercise 2 that a body going from air into water lost in apparent weight an amount equal to the weight of its own bulk of water. So a body going from air into a solution of sulphate of copper will lose in apparent weight an amount equal to the weight of its own bulk of the solution. This gives a method of finding the specific gravity of the solution. As a *body* to be weighed first in air, then in water, then in the solution, we will use the bottle with enough water in it to make it sink in either liquid. We may, indeed, use the bottle *full* of water, just as it was left at the end of the first part of this Exercise.

---

* This solution may be made by putting 2 lbs. of sulphate of copper crystals into about 3 qts. of *warm* water in a glass vessel and stirring occasionally till the crystals are dissolved.

EXERCISE 8.

THE STRAIGHT LEVER: FIRST CLASS.

Apparatus: The lever and supporting bar (No. 17) fastened to the long horizontal bar that reaches above the table from end to end. Two scale-pans (Nos. 18A and 18B). A set of weights (No. 19).

Hang one scale-pan carrying a load of 8 oz. on the right-hand end of the lever at a distance of 14 cm. from the middle, as in Fig. 21.

Hang the other pan, with an equal load, on the left-hand end of the lever, at such a distance from the middle that the lever will *balance*, that is, stay horizontal when once placed so, even when the apparatus is jarred somewhat by tapping the short bar to which the lever is attached. Then make a record like this:

Left wt.	Left dist. fr. centre	Right wt.	Right dist. fr. centre.
$(1 + 8) = 9$ oz.	. . . . .	$(1 + 8) = 9$ oz.	14.0 cm.

(The space here left blank, in the record, is to be filled by the left-hand distance which the student finds necessary to make the apparatus balance.)

Change the right-hand weight to 7 oz., keeping its *place* unchanged, and move the left-hand weight, still 9 oz., to some new position which will make the whole balance, in spite of jarring as before. Make a record, as before of the weights and distances, putting it just beneath the record for the first arrangement.

Change the right-hand weight to 5 oz. without changing its place, and find what position the left-hand weight, still remaining 9 oz., must have in order that the lever may balance. Record the distances and weights for this case under the records already made for the first and second cases.

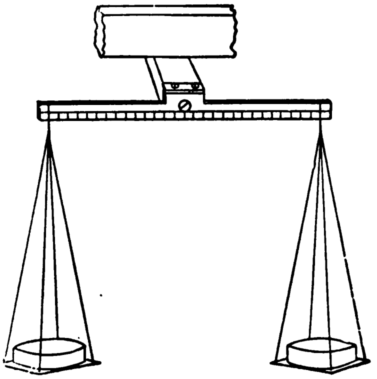

Fig. 7.

One more case may be taken, in which the right-hand weight becomes 4 oz., still at 14 cm., which will give a fourth line in the record table. More observations with different arrangements might be made, but it is better to make a moderate number of good observations than a large number of hasty or careless ones.

By studying the record table now made the student should find a rule by which, when the two weights and one distance are given, the other distance can be found by calculation; or when the two distances and one weight are given, the other weight can be found by calculation.

EXERCISE 9.

CENTRE OF GRAVITY AND WEIGHT OF A LEVER.

Apparatus: The lever of No. 17, detached from its supporting bar, and a small block (No. 21), the two being fastened together, as in in Fig. 8, so as to make one body the whole of which will be called the lever in this Exercise. A slender wooden cylinder (No. 13). A 1-oz. scale-pan (18 A or 18 B). A 1-oz. wt. from No. 19.

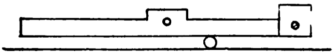

FIG. 8.

To find the centre of gravity of the lever, balance it as nearly as you can, bar and block fastened together, in a horizontal position on the cylinder laid on the table (see Fig. 8), the cylinder being kept at right angles with the lever. Find in this way at what particular mark of the bar the centre of gravity is, and record this mark — for example, 9.1 cm.

Then suspend the 1-oz. scale-pan carrying a 1-oz. wt., 2 oz. in all, from any convenient point near the free end of the bar, and letting this end project beyond the edge of the table-top, balance the whole, as now arranged, as nearly as you can, on the cylinder laid on the table as before (see Fig. 9).

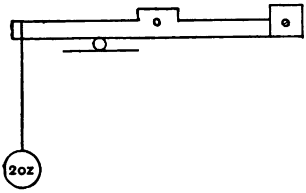

FIG. 9.

Now record the mark from which the scale-pan hangs, 33.4 cm., we may suppose, and the mark which is just over the middle of the cylinder when the whole balances, 21.6 cm., let us say.

This case is like that of the lever studied in Exercise 8. The cylinder now taking the place of the screw as a support, we see that

the left-hand weight is 2 oz.,
" " " distance is $33.4 - 21.6 = 11.8$ cm.,
" right-hand weight is the weight of the lever,
" " " distance is $21.6 - 9.1 = 12.5$ cm.,

that is, the distance from the support in Fig. 9 to the centre of gravity of the bar and block.

We do not as yet know the weight of the lever, but we can call it W_2 and see whether we can find its amount by calculation. If we apply the same rule that was found to hold true in Exercise 8, we shall have

$$2 \times 11.8 = W_2 \times 12.5,$$

which gives for the weight of the bar and block

$$W_2 = \frac{2 \times 11.8}{12.5} = 1.89 \text{ oz., nearly.}$$

The value of W_2 obtained in this way by the pupil should be compared with the weight of the bar and block as found by the teacher with some balance, much more sensitive than the spring-balance used by the class; for if the method of this Exercise is carefully followed it will give the weight of the lever more accurately than the spring balance is likely to do.

EXERCISE 10.

LEVERS OF THE SECOND AND THIRD CLASSES.

Apparatus: The lever (No. 17) supported as in Exercise 8. A scale plan (No. 18). A set of weights (No. 19.) A spring-balance (No. 7.)

Suspend the pan with a load of 8 oz. at a point 5 cm. from the middle of the lever, and, on the same arm of the lever, at a distance of 10 cm. from the middle, pull upward with a spring-balance, connected with the lever by means of a loop of thread, until the weight is balanced and the lever becomes horizontal. You have here a lever of the second class. Read the spring-balance and record as follows:

LEVER OF SECOND CLASS.

Weight.	Weight-arm.	Power.	Power-arm.
9 oz.	5 cm.	. . . .	10 cm.

Try other similar cases, and study them all until you are able to write down the law for this class of levers.

Then with the same apparatus place the spring balance between the fulcrum and the line of the weight. You will now have a lever of the third class. Try various cases and record as before.

LEVER OF THE THIRD CLASS.

Weight.	Weight-arm.	Power.	Power-arm.
. . . .	. . . .	. . . .	. . . .
. . . .	. . . .	. . . .	. . . .

Law . . . .

EXERCISE 11.

FORCE EXERTED AT THE FULCRUM OF A LEVER.

Apparatus: The lever of No. 17 freed from its support. Two scale-pans (Nos. 18A and 18B). Two 1-oz. wts. and one 2-oz. wt. from No. 19. The spring-balance (No. 7). A piece of copper wire about 1 mm. in diameter bent into the form of a hook (*h* in Fig. 10). A piece of thread about 15 cm. long.

Suspend the bar from the balance in the manner indicated by Fig. 10. Note and record the weight of the bar alone. Then suspend one scale-pan with a 1-oz. weight from one arm of the bar, and the other scale-pan with a 2-oz. weight from the other arm in such a way as to balance, taking care not to let the pans and weights spill. Note and record the reading of the balance. Then make the loads (pan and weight) 2 oz. on one side and 4 oz. on the other, and read and record. Try any other experiments that you can with the weights furnished, until you feel reasonably sure that you know the relation between the weights applied and the pull on the balance. Then state what this relation is.

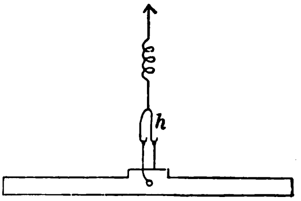

Fig. 10.

EXERCISE 12.

ERRORS OF A SPRING-BALANCE.

Apparatus: A spring-balance (No. 7). A set of weights (No. 19). Thread for suspending the weights. A measuring-stick (No. 3). (Although weights reckoned in ounces are referred to in this Exercise, it may be performed equally well with suitable weights reckoned in grams).

Balance in the Vertical Position.—Suspend the balance by its ring from some convenient support so that the index will be not higher than the eye of the observer.

Make five careful readings with the loads indicated in the first column below, and record these readings in a second column; thus, for example:

True Load.	Reading.	Error.[*]
0 oz.	—0.2 oz.	—0.2 oz.
2 "	2.0 "	0.0 "
4 "	4.2 "	+0.2 "
6 "	6.3 "	+0.3 "
8 "	8.1 "	+0.1 "

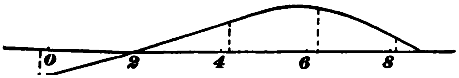

Fig. 11.

Now draw in the note-book a straight line a little more than twice the length of the scale of the balance, and mark off on it points corresponding to the *loads* and *readings* given below.

Then represent the errors by vertical distances, measured *down* from the points indicating the *readings* when the errors are negative, and *up* when they are positive, showing these errors on a rather large scale, 0.5 cm. per 0.1 oz., for instance.

Draw a curve through the extremities of these vertical distances, as in Fig. 11. This curve will enable us to tell with sufficient accuracy for our present purposes the errors of any other readings made with the balance in the vertical position; for instance, if the balance to which Fig. 11 relates *reads* 1 oz., we may assume that the error is very nearly 0.1 oz. and that the true weight is very nearly 1.1 oz.; if the reading is 3 oz., we may assume that the true weight is about 2.9 oz., and so on, the error for each case being found by measuring from the point indicating the reading up to or down to the curve.

The Same Balance in the Horizontal Position.—We will suppose at first that the same index is used for the horizontal as for the vertical readings.

Lay the balance flat on its back and tap it gently several times.[†]

[*] That is, the quantity which must be *subtracted* from the *reading* in order to find the true weight.

[†] This method assumes that the movable parts of the balance are restrained by friction only, which the tapping overcomes. Sometimes the slot in the balance-face is not long enough to allow the index to find its unrestrained position.

Then take its reading, which we will suppose to be — 0.5 oz. In this case it would require a force of 0.3 oz. to pull the index down to the position it occupied with no load in the vertical test. To bring the index to any reading in the horizontal use of this balance will, therefore, require a force 0.3 oz. greater than the weight which, applied to the hook in the vertical use of the balance, would bring the index to the same point.

It would in the case here supposed be sufficiently accurate for our purposes to add 0.3 oz. to any horizontal reading, and then correct this increased reading by means of the curve given in Fig. 11.

When a different index is used for horizontal readings, the principle is the same. For example, let us suppose the second index reads — 0.1 without pull in the horizontal use of the balance. We say, this reading exceeds the vertical reading without load by 0.1 oz. We must therefore, subtract 0.1 from all horizontal readings made with this second index, and then correct these reduced readings by means of the curve in Fig. 11.

The curve so often referred to should be marked with the number of the balance and kept for future use.

EXERCISE 13.

THREE FORCES IN ONE PLANE AND ALL APPLIED AT ONE POINT: PARALLELOGRAM OF FORCES.

Apparatus: Three 8-oz. spring-balances, each provided with two small blocks (No. 22) to go under its sides and hold it flat on its back when it is lying upon the table. The rectangular block (No. 9). The measuring-stick (No. 3). A sheet of paper. Thread.

Take two pieces of strong thread, one about 12 inches, the other about 6 inches long, and tie one end of the short thread to the middle of the long one. Fasten the three loose ends to the hooks of the spring-balances; then lay the latter upon the table, putting the blocks under their sides, as in Fig. 12, and let one student pull at each balance, taking care that the slit of each balance-face is in a straight line with the thread, until no one of these reads less than 3 oz.

It will be found that any variation in the angles which the strings make with each other will require a change in the forces. Evidently there is some connection between the directions of the strings and the forces necessary to balance each other. The object of this Exercise is to make out what this connection is.

Put under the threads a sheet of paper, and draw on this paper, just under each thread, a pencil mark parallel to the thread, and then write down alongside each pencil-mark the force in the direction of that line, as shown by the spring-balance. The balances must be held very still while these lines are being drawn, and must be read before any change occurs in the direction of the lines.* To draw a line place one side of the block (No. 9) close alongside one branch of the thread, taking care not to push the thread out of place, and then run the point of a well sharpened pencil along the edge of the block under the thread. Draw the other lines in the same way, doing all very carefully.

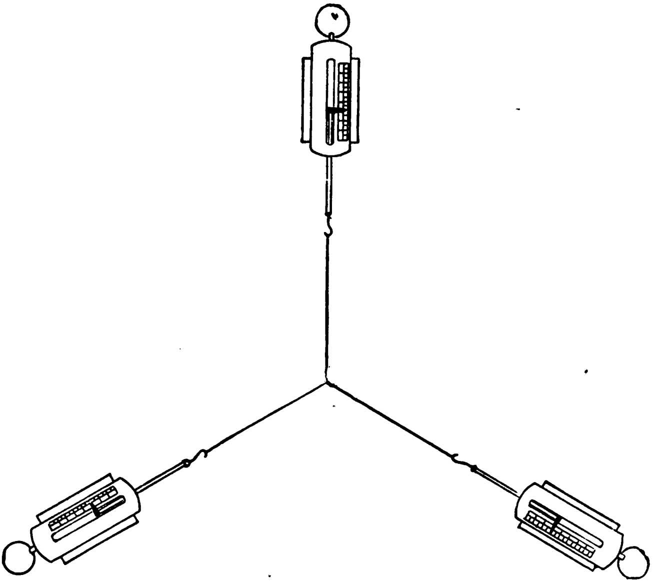

Fig. 12.

Each student in turn should make a set of lines, and record alongside them the proper forces. The directions of the pulls should be varied somewhat by each experimenter, in order that his lines and forces may not be exactly like those of others.

---

* It is well to fasten the *ring* of each balance to some object heavy enough to hold the balance in place, thus relieving the experimenters, who might grow tired and unsteady in holding the balances long enough to permit of drawing the pencil marks properly.

Take now the wooden ruler (No. 3) and extend the three lines toward each other till they meet at one point. This they will do if they have been drawn originally just *under* the threads. If they do not meet at one point, a new line should be drawn parallel to one of them in such a position as to pass through the crossing of the other two lines, and this new line, the dotted line in Fig. 13, is then to be used in place of the original line. The three lines as now drawn will represent accurately the *directions* of the forces.

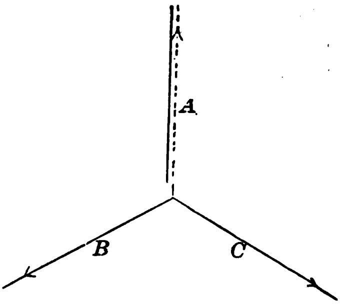

Fig. 13.

Now measure off from the common point along the line *A* a distance of 1 cm. from each ounce (or each 30 gm., if the forces are measured in grams) of the force which was exerted along that line, and put a small arrow-head (see Fig. 13) at the end of this measured distance. Erase that part of line *A* which lies beyond the arrow-head.

Do the same with lines *B* and *C* that has been done with *A*. The three arrows thus obtained, all reaching from the same point, represent the magnitude and the direction of the three forces exerted by the spring-balances.

Now with *A* and *B* of Fig. 13 as two of the sides draw a parallelogram, taking pains to make it accurate.* Then make a parallelogram

---

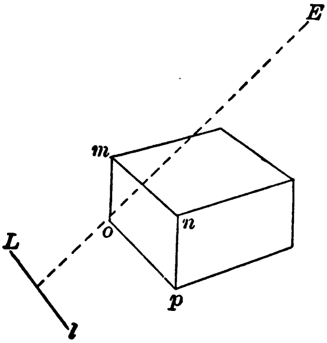

Fig. 14.

* One line may be drawn very nearly parallel to another by means of a device illustrated by Fig. 14. *Ll* is a line already drawn. The block (No. 9) is so placed that for an eye placed at *E* the edge *mn* appears to be close to *Ll* and parallel to it. Then a pencil-mark is made along the edge *op*.

A better method is to set the edge *op* on the line *Ll* and then guide the block to a new position by sliding it along the straight edge of a ruler at right angles with *Ll*.

with B and C as sides, then one with A and C as sides. Compare the length and direction of the line C with the length and direction of the diagonal of the parallelogram AB; the line A with the diagonal of the parallelogram BC; the line B with the diagonal of AC.

From a study of this Exercise make a rule showing how to find the direction and magnitude of a force C which put with two other forces represented by lines A and B, meeting at a point, will just balance them.

EXERCISE 14.

FRICTION BETWEEN SOLID BODIES.

Apparatus: A spring-balance (No. 7). A rectangular block (No. 9). Set of weights (No. 19). A smooth sheet of paper about 1 ft. wide and 1½ ft. long. Thread.

We shall first consider the velocity of the motion, that is, we shall ask whether the force required to keep up a slow steady motion is greater or less than that required to keep up a more rapid steady motion.

Lay the block on one of its broad sides, and attach it to the spring-balance by a thread passing around but not under the block. Load the block with weights until the force required to maintain a slow steady motion is about 3 oz. Draw the block parallel to its *grain* along the sheet of paper several times with a very slow steady motion, and then several times with an equally steady motion two or three times as fast. (As the paper is likely to grow somewhat smoother under the repeated rubbing, the experimenter should not make all his slow trials first, but should change from slow to fast and fast to slow a number of times.)

Record your conclusion as to whether the slow or the more rapid motion require the greater force.

We shall next try to find out whether, the total weight being the same as before, it is easier or harder to draw the block on a narrow side than on a broad side.

Use the same block and the same load of weights, pulling it now, as before, parallel to its grain.

(The side upon which the block slides should in all cases be clean, and the broad and narrow sides which are compared should be, as nearly as practicable, equally as smooth. The thread must not be between the rubbing surfaces in any case.)

Record your conclusion as to whether the broad side or the narrow side offers the greater resistance to the motion.

Finally, we shall ask what connection there is between the total mass drawn and the force required to draw it.

For this purpose vary the weights placed upon the block, using not less than 6 oz. for the least and as much as 16 oz. for the greatest load.

Add to the load in each case the weight of the block itself, and make the record in the following form, W being the load and b the weight of the block:

$W + b$.*	F (Force Required).
. . . .	. . . . .
. . . .	. . . . .
. . . .	. . . . .

Look for any simple relation between $(W + b)$ and F.

The experiments just described will teach a number of useful facts about friction between two solid substances, but one must be careful not to apply the conclusions here arrived at to extreme cases, extremely slow or very fast motion, for instance; or to cases where the pressure is great enough and the edge of the sliding body narrow enough to cause an actual cutting of the body into the surface over which it should slide.

EXERCISE 15.

COEFFICIENT OF FRICTION.

Apparatus: The same block that was used in Exercise 14. A flat board (No. 20) about 15 cm. wide and 50 cm. long for the block to slide on. A sheet of paper to cover one side of this board. Some means of raising one end of the board and adjusting it so that the block will slide down it; another block similar to the one which slides, or any similar object, will do for this purpose. A 30-cm. measuring-stick.

Place one end of the board on the table and the other on the support. Vary the steepness of the board by varying the position of the support, until such an inclination is found that the block, once started slowly, will barely continue in motion down the board.

---

* It is well to begin with the lightest load, proceed in regular order to the heaviest, then go back in the regular reverse order to the heaviest, recording both trials made with each load and taking the mean of the two for final study.

Then lay off on the table beneath the board a distance of 30 cm., measured from the edge where the board rests upon the table, and from the end of this line measure H, the vertical distance up to the under side of the board. The coefficient of friction will be $H \div 30$.

If the same block, the same side of the block, and the same kind of paper are used in this Exercise as in Exercise 14, the value of the coefficients obtained in the two Exercises should be compared.

LIGHT.

EXERCISE 16.

USE OF RUMFORD PHOTOMETER.

Apparatus: Two small kerosene lamps like No. 33. A cardboard screen and its support (No. 32 and No. 21.) Any opaque rod about 1 cm. in diameter and 10 or 15 cm. tall, supported upright; e. g. No. 13 standing in a hole bored in a small block, or a Bunsen burner. A meter rod.

The object of the experiments will be to find whether a flame sends more or less light from its broad side than from its edge, and, if so, how much. The flame should be made as large as they can well be without smoking.

The apparatus should be arranged as in Fig. 15.

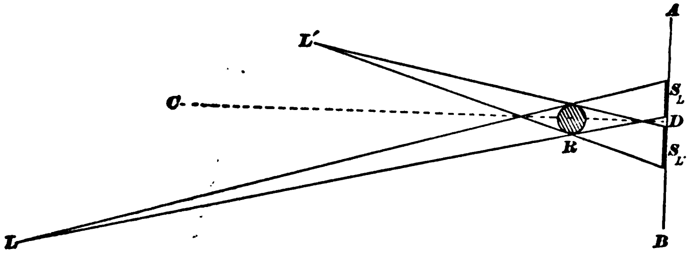

Fig. 15.

L is one of the lamps to be compared, and L' the other; R the rod, AB the screen, and S_L and $S_{L'}$ the shadows. The lamps should be so arranged that lines drawn from their centres to the centre of R will make nearly equal angles at R with the line CD, drawn at right angles to the screen through the centre of R, and on this line the observer should be placed. The shadows should be near each other, but must not overlap.

It is plain that the shadow corresponding to L is illuminated by light from L' and that the one corresponding to L' is illuminated by light from L.

Place the lamps equidistant from the rod, and, shielding the eyes from the direct light of the flames, adjust the flames, turned edgewise to the rod, until the shadows are of equal darkness.

Then turn one of the lamps about in place until its flame is flatwise to the rod, and compare the shadows again, fixing the attention upon the middle of the more blurred one. If the shadows still appear to be of equal darkness, record the fact. If they do not, move one of the lamps toward or from the rod until the shadows appear equally dark, and then record the distance of each flame from the corresponding shadow.

Try each lamp in turn flatwise, the other being edgewise. Between the trials test the flames again in their original position, to make sure that they are still equal.

If, on the whole, it appears that one aspect of the flame, broad side or edge, is more effective than the other, estimate the relative light-giving power of the two aspects from the measured distances, making use of the law of inverse square.

EXERCISE 17.

IMAGES IN A PLANE MIRROR.

Apparatus: A mirror (No. 23). A rectangular block (No. 9). A rubber band to hold the mirror to the block. Two straight-edged wooden rulers (Nos. 24A and 24B). A measuring-stick (No. 3). A sheet of thin white paper about 12 inches by 20 inches. A small block (No. 25). Attach the mirror to the large block by means of the rubber band in the manner shown by Fig. 64.

Draw a straight pencil-mark across the sheet of paper at its middle, and set the *back* surface of the mirror directly over and parallel to this line, the middle of the mirror being very near the centre of the sheet. See Fig. 16.

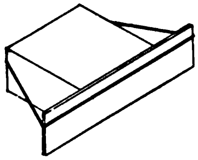

Fig. 16.

Draw on the sheet of paper in front of the mirror a triangle, each side of which shall be several inches long, and no corner of which shall be several inches long, and no corner of which shall be less than three inches from the mirror. It is well to have one angle of the triangle not directly in front of the mirror, but somewhat to one side, like No. 1 in Fig. 17.

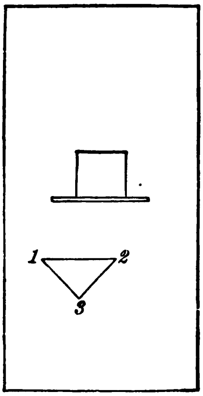

Fig. 17.

Place the small block in such a position that the vertical pencil-mark which it bears shall be directly over point No. 1 of the triangle. Then lay a straight-edged ruler (Fig. 18), upon the paper in such a position that one of its long horizontal edges, *PQ*, shall point directly toward the image of the vertical pencil-mark, as seen in the mirror.* The ruler should be so placed that the line of sight will strike near one end of the face of the mirror. Then with a well-sharpened pencil draw upon the paper a fine clear mark alongside that edge of the ruler which lies just beneath the line *PQ* (Fig. 18) along which the *sight* has been taken. Mark this line 1, because it points toward the image of the vertical pencil-mark when this mark is over point No. 1.

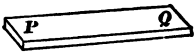

Fig. 18.

Next, without disturbing anything else, place the ruler in a new position, far removed sidewise from the position just occupied, sight as before, draw another line alongside the ruler, and mark this line also 1.

Then with the ruler in a new position, about half-way between the first two, if this is convenient, draw a third line in the same way, and mark this also 1.

All this time the small block has remained unmoved, and the pencil-mark upon it has pointed straight down at point No. 1.

Now place the small block so that the pencil-mark shall point straight down at point No. 2. While it is in this position draw three straight lines toward the image and mark each one of these 2.

---

* Many persons cannot do this at first unless they are especially instructed. A person who is not near-sighted should hold his eye eight or ten inches distant from *P*, and should then direct the ruler in such a way that the *point P*, the *point Q*, and the image of the vertical pencil-mark seen in the mirror shall all lie in one straight line. Do not try to look along the vertical *side* of the ruler, but hold the eye high enough to see all the time the top of the ruler.

Finally, put the pencil-mark over point No. 3, draw three straight lines toward its image, and mark each of them 3.*

When the three sets of lines have been drawn, the two blocks and the mirror are removed from the paper, and each line is then lengthened † until it crosses both the others of the same set; that is, each No. 1 line is continued toward or beyond the mirror till it crosses the two other No. 1 lines. Then the No. 2 set and the No. 3 set are treated in the same way.

After each set of lines has been extended in this way, it will be in order to answer the question whether all the lines of any one set lead to the same point or nearly so, and, if so, where is this point situated with respect to the mirror and to the point whose image it is.

If the image of each point, No. 1, No. 2, and No. 3, can be thus found, connect the image-*points* with each other by straight lines, and thus make an image-*triangle*.

The general rule for placing the image of any point should be recorded when it is found.

The final result aimed at in this Exercise should be to enable the student to tell, without further experiment, in any new case given him (Fig. 20, for instance, in which $A\,B$ is the line upon which the mirror stands), the position of the image of points No. 1, No. 2, No. 3, and No. 4, and so the shape and position of the image of the figure at the corners of which these points lie.

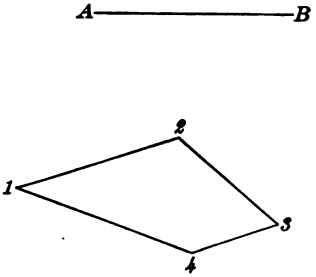

Fig. 20.

---

* While drawing all these lines the experimenter should look frequently to see whether the back of the mirror remains in place. It may be thrown out of place by a little blow or by rubbing the paper hard to remove pencil marks.

† If a line has to be extended far it is well to use two rulers, *A* and *B*, as shown in Fig. 19. First *A* is put into position and a line is drawn alongside it. Then, while *A* remains unmoved, *B* is carefully brought close to it, as the figure shows; then *B* is held firmly in place while *A* is pushed forward to the position indicated by the dotted lines. *B* is then removed without disturbing *A*, and again a line is drawn alongside *A*. In this way a line may be continued nearly straight for a considerable distance.

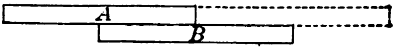

Fig. 19.

EXERCISE 18.

IMAGES FORMED BY A CONVEX CYLINDRICAL MIRROR.

Apparatus: The mirror (No. 27). A measuring-stick (No. 3). Small block (No. 25). Rulers (No. 24 A and B.) Sheet of white paper. The plane mirror (No. 23) and its supporting block (No. 9.)

Hold the mirror with its straight edges vertical, and look at the image of your own face in the convex surface. You will see that the image is distorted, appearing too narrow for its length. Hold the mirror with its straight edges horizontal, and the image will be distorted in the opposite way, appearing too wide for its length. The object of the following experiments is to give a better understanding of these curious effects.

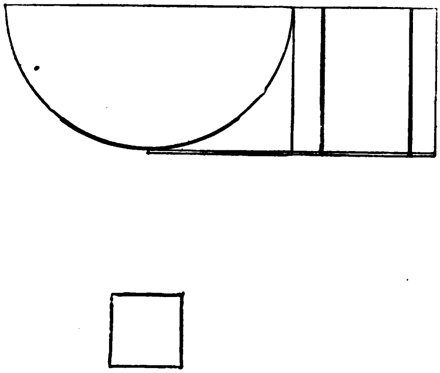

Fig. 21.

Set the mirror on the table and bring one end of the plane mirror close to the surface of the curved mirror, as in Fig. 21. Then place the small block in front of both mirrors, as in Fig. 21, in such a position that you can see the block reflected in both mirrors at the same time.

Do the two images thus seen appear to be of the same height?

Do they appear to be of the same width?

Fill out, if you can, the following statement: *Lines of the object which are parallel to the straight lines of the cylindrical mirror appear*..............................*in the cylindrical mirror*.................................... *plane mirror.*

Lines of the object which are at right angles with the straight lines of the cylindrical mirror appear..................................*in the cylindrical mirror*................................*in the plane mirror.*

Remove the plane mirror. Holding the base of the curved mirror firmly in place, make a fine, clear, pencil-mark on the paper along the outer edge of the mirror. Then mark on the paper the point C, Fig. 22, which is the *centre of curvature* of the mirror.

About 5 cm. from the front of the mirror draw an arrow 6 cm. long, marking the ends and the middle as in Fig. 22. Then place the small block so that the vertical pencil-mark which it carries will point straight down at point No. 1.

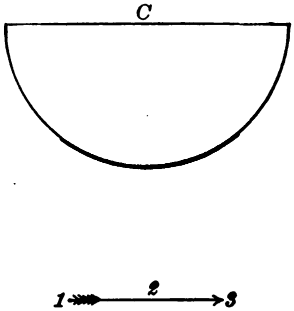

FIG. 22.

With the straight-edged ruler draw two lines, well apart, toward the image of this vertical line as seen in the mirror, avoiding parts of the mirror, if there are such, that do not give a good image of the line. Mark each of these lines 1. Then draw two lines for point No. 2 and for point No. 3, in the same way.

Then clear the paper and prolong each pair of lines till it comes to a crossing-point. The three points thus found will locate the images of object-points No. 1, No. 2, and No. 3, respectively, and a line connecting these three image-points will give an idea of the shape of the image-arrow, whether it is straight or not, and whether its curvature, if it has any, is in the same general direction as the curvature of the mirror in the opposite direction.

Draw a straight line from each marked object-point to the corresponding image-point, and prolong these three lines until they cross each other? Note where the crossing occurs.

Is the image longer or shorter than the object? Is it nearer to, or farther from, the mirror than the object is?

(It must be understood that the pupil is asked these questions only in regard to the particular case that he has tried. He cannot tell without further experiments or further instruction whether the answers he gives in this case would be true for all cases of objects reflected in mirrors such as he is using, for he does not know that the distance of the object from the mirror may not decide all these questions. The fact is, however, that, if he has found correct answers to the questions asked for this one case, the same answers will be true for the same questions in all cases with *convex* cylindrical mirrors. The effects seen with *concave* mirrors are much more complicated.)

EXERCISE 19.

IMAGES FORMED BY A CONCAVE CYLINDRICAL MIRROR.

Apparatus: The same as in the preceding Exercise, and in addition a common pin.

Preliminary.

Remove the mirror from the base-board; place the latter upon the paper; and mark on the paper the point *C* and the curved outline of the board.

Make the distance *CA* 4.2 cm., and draw the arrow *A* 4 cm. long. Draw radii from *C* through the ends of *A*.

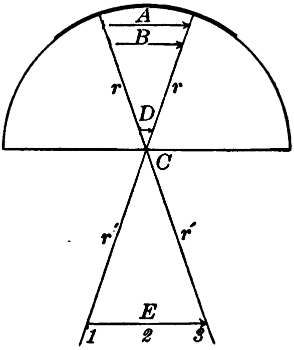

Fig. 23.

Make the distance *CB* 3.5 cm., and draw *B* from radius to radius.

Make the distance *CD* 1.5 cm., and draw *D* from radius to radius.

(All this should be done before the regular Exercise begins.)

Place the mirror in position as in Fig. 23, and, keeping the eye about 20 cm. from it, look at the images of *A*, *B*, and *D*.

Do the images of *A* and *B* point in the same general direction, from left to right in the figure, as the arrows themselves?

Is the same answer true of *D* and its image?

Are the images of *A* and *B* longer or shorter than the arrows themselves?

At the centre of *A* stand the pin upright, and laying the two rulers on the paper, point one edge of each toward the image of the pin, contriving to have these edges make a considerable angle with each other. In this way the position of the image is located. Is it behind the mirror or in front? Is it, then, a real image or an unreal one?

By the same method locate the image of the pin when erected at the centre of *B* and when at the centre of *D*, asking and answering in each case the same questions that were asked when the pin was at the centre of *A*.

If time permits continue the Exercise as follows:

Extend the two radii *r r* by the lines *r′ r′* drawn on the paper, as in Fig. 23. Draw the arrow *E*, 6 or 8 cm. distant from *C*, marking points 1, 2, and 3, upon it. Locate the image of each of these points by the method used in the preceding Exercise with the convex side of the mirror, drawing upon the paper the lines of sight and the image of the arrow.

EXERCISE 20.

INDEX OF REFRACTION OF GLASS.*

Apparatus: A piece of plate glass (No. 28). Articles 3, 24A and 24B. A sheet of paper and three pins.

Place the glass, *G* (Fig. 24), on the paper *P*. Stick one pin upright at the point 1 close to one of the polished edges of the glass; stick the other pin at 2 close to the other polished edge.

Look with one eye from the position *S through* the whole width of the glass at pin No. 1. Move the eye toward 3, looking all the time through the glass at the pin. It will presently be noticed that the pin seen *through* the glass is not in the same direction from the eye as the same pin seen *over* the glass. That which is seen through the glass is an *image* of the real pin, and it is upon this image that the attention should be fixed.

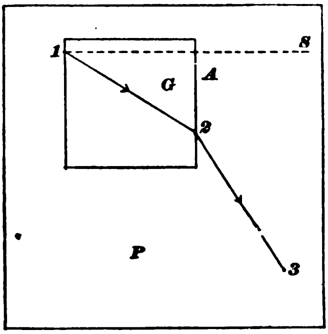

FIG. 24.

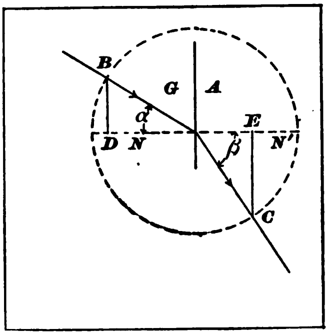

FIG. 25.

Continue moving the eye in the general direction of 3, keeping it, however, about 30 cm. from the glass, until the image of pin No. 1

---

* I owe the plan of this admirable Exercise to Mr. F. M. Gilley of the Chelsea High School. It is described in Gilley's *Principles of Physics*, Allyn & Bacon, Boston. — E. H. H.

is just hidden behind pin No. 2. Then place a pin at 3, in the same straight line with the eye, pin No. 2, and the image of No. 1.

Draw a fine pencil-line upon the paper close to the glass edge touched by pin No. 2. Then remove the glass.

The line now drawn marks the position of the refracting surface. The line 1–2, Fig. 24, shows the direction, within the glass, of a certain ray from 1. The line 2–3 shows the course of the same ray after it leaves the glass at 2. The line NN', Fig. 25, is drawn normal to the refracting surface at the point of emergence. From this point equal distances are laid off, to B and to C. Lines are drawn from B and from C to the line NN' at right angles.

$CE \div BD =$ *the index of refraction from air to glass.*

EXERCISE 21.

INDEX OF REFRACTION OF WATER.

Apparatus: Articles 3, 14, 15, 24A, 24B, 29, 30, and a sheet of paper about 6 inches square.

Put the partition N in place, as shown in Fig. 26, and pour water into the jar until its surface comes within 1 or 2 mm. of the middle tooth of the partition. Then by means of the plunger (No. 14), attached to the side of the jar by means of its clasp, raise the level of the water till the apparent distance between the middle tooth of the partition and its reflection in the water surface is less than 1 mm. (To see this reflection well, one should look through the wall of the empty part of the jar.)

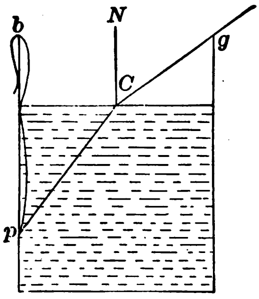

Fig. 26.

Then the brass index b is attached to the jar, as shown in Fig. 26, and is raised or lowered, *with the tip p touching the glass*, until an eye on the line Cg, 20 or 30 cm. from the jar, can barely see p, the very tip of b, apparently in a straight line with Cg. This setting should be made with care, and *after* it is made the experimenter must look to see whether the tooth at C is clear of the water. If its lowest edge touches the water the setting is useless, and all of the adjustments must be made anew before a reading is made.

When all the adjustments have been successfully made, measure carefully the distance from the top of the jar down to the tip, p, of the index, the measuring-stick being kept outside the jar.

Measure now the inside diameter of the jar.

Measure also, unless it is already known, the distance[*] of C below the top of the jar.

Now make a drawing, of full natural size, of the sides of the jar (inner lines), the water surface and the partition, as in Fig. 27, continuing the partition line, by means of dots, well down into the jar.

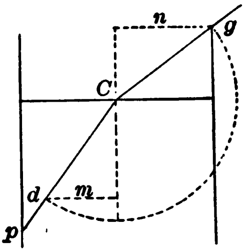

FIG. 27.

Put p in its proper place, and then draw the lines pC and Cg.

Lay off $Cd = Cg$, and then draw the lines n and m.

The index of refraction from air to water is $\frac{n}{m}$.

EXERCISE 22.

FOCAL LENGTH OF A CONVERGING LENS.

Apparatus: The lens (No. 31) mounted on a block. A meter-rod (No. 2). A small block (No. 21) bearing a white cardboard screen (No. 32). A common pin.

FIRST METHOD.

Place the lens and the screen upon the rod, as in Fig. 28, and point the rod at some distant object, seen against the sky, in such a way that the light from this object will pass from the lens and then fall upon the screen. Move the screen back and forth until that part of the image[†] which lies on or near the principal axis of the lens is made as distinct as possible. Then by means of the graduations of the meter-rod, or by an independent measuring-

---

[*] It is well to have this distance, which is somewhat troublesome to measure accurately, given by the teacher. Partitions of different depths might be used in order to vary the angles of incidence and refraction.

If the jar used in this Exercise is not pretty level at the top, or if the partition is not just at the middle of the jar, it is well, after making one setting of the index and one measurement of its position, to turn the jar about, transferring the index to the other side, and make a new setting and a new measurement. The *mean* of the two measurements thus made should be nearly free from any error caused by irregularity of the jar or of the partition's position.

[†] The image is formed because light coming from any one small spot of the object is brought to a small spot again by the lens. The image is made up of

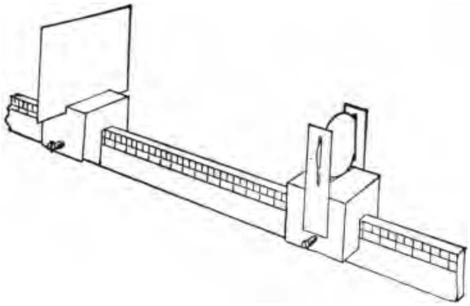

FIG. 28.

stick if this is preferred, note the distance from this part of the image to the nearer face of the lens. This is the *focal length.*

SECOND METHOD.

Remove the screen from its block and put the pin upright in its place. Let the pin, thus mounted, be placed on the meter-rod, about as far from the end of the rod as the pupil usually holds a book from his eyes when reading. Place the lens somewhat farther from the same end of the rod.

Place the eye at this end of the rod and, looking sharply at the *pin,* direct the rod and adjust the lens in such a way that the light from some distant object will pass through the lens and form an image *in the air* close to the pin. To decide whether the image is nearer the eye than the pin is, move the eye to and fro, to the right and the left, watching the pin and the image.* If the pin is more distant than the image, it will, when the eye is moved toward the right, appear to move across the image toward the right. If the pin is nearer than the image, it will, when the eye is moved toward the right, appear to

---

such small spots each in its own place. For the purposes of this Exercise the *distant* object need not be more than 30 or 40 feet from the experimenter. The images on the screen will be much more distinct if the apparatus is used in the back part of the room, well away from the windows.

* To see the reason of the test just described, close one eye and hold the two forefingers, some inches apart, in line with the other eye, so that one finger hides the other. Then move the eye to the right and left, and notice the apparent movement of the fingers with respect to each other.

move across the image toward the left. The rod should not be held in the hands during this test, but should be placed on some steady support.

Continue the adjustments until the test described fails to show which of the two, the pin or the image, is nearer the eye. Then measure the distance from the pin to the lens. It should be the focal length of the lens.

Compare the values of the focal length given by the two methods. The second method is more difficult, but it is instructive, and it can be used in cases where the image is too faint to show clearly upon the screen.

EXERCISE 23.*

RELATION OF IMAGE-DISTANCE TO OBJECT-DISTANCE: CONJUGATE FOCI OF A LENS.

Apparatus: The same lens that was used in Exercise 22. A meter-rod. Block (No. 9). Small block (No. 21), with a card-board screen (No. 32). Small kerosene lamp with an asbestos band around the chimney (No. 33).

Arrange the apparatus according to Fig. 29. The hole in the asbestos band, lighted up by the flame behind, is the *object* the image of which is to be received upon the screen. One end of the meter-rod is placed vertically beneath this illuminated hole.

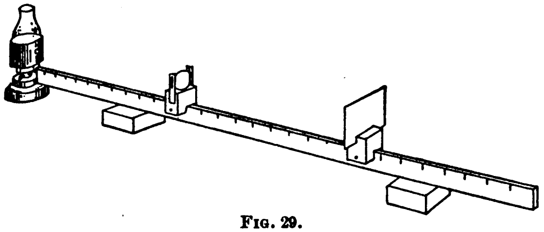

FIG. 29.

Place the screen at first at a distance from the object about equal to three times the focal length of the lens. Then move the lens back and forth on the rod between the object and the screen, and see whether in any position it gives upon the screen a clear image of the object. If it does, measure the distance from the lens in this position to the object, and write this distance as the first number in a record-column headed D_o (object-distance). Measure also the distance from the lens to the screen, and put this distance as the first number in a record column headed D_i (image-distance).

---

* To economize space upon the laboratory-tables it will probably be necessary to have pupils work in pairs in this Exercise. Each pair should know the focal length of its lens at the outset, so as to lose no time in beginning the Exercise.

If, with the present position of the screen and object, there is no position of the lens that will cause a distinct image of the object to fall upon the screen, move the screen one or two centimeters farther from the object, and then try again to get a good image. If still none is found, move the screen still farther away, continuing the trial till a distinct image is obtained. Then measure and record the D_o and D_i as already described. (Very little time need be spent upon these first successive trials.

Then at one move place the screen about 10 cm. farther still from the object, find a position of the lens that will give a distinct image, measure and record D_o and D_i as before. Without moving the screen, see whether there is any other position of the lens that will give a distinct image; if there is, measure and record the D_o and D_i for this position of the lens.

Move the screen 10 cm. farther away, and then do exactly as before.

If there is time, move the screen two or three more times, adjusting the lens, measuring, and recording each time. It is better to make a moderate number of settings and readings well than a large number carelessly, but an error of one or two millimeters in these readings will be of no great consequence.

EXERCISE 24.

SHAPE AND SIZE OF A REAL IMAGE FORMED BY A LENS.

Apparatus: The lens (No. 31). Measuring-stick (No. 3). Block (No. 21) carrying in the narrow slot on its top a piece of wire (No. 34) extending first horizontally and then downward (see Fig. 31). A ruler (No. 24). Block (No. 25). A sheet of paper about 30 cm. wide and 1 m. long, having near one end an arrow 8 cm. long, drawn at right angles with a pencil-mark about 30 cm. long, and marked, or numbered, as shown by Fig. 30. Weights (No. 19) to hold the corners of this sheet in place on the table.

Arrange the apparatus as shown by Fig. 31, the centre of the lens over a point on the long pencil-mark, at a distance from the centre of the arrow about equal to one and a half times the focal length of the lens, and block No. 25 in such a position that the vertical mark upon its face points straight down to point No. 3 of the arrow. This vertical mark will now cross the principal axis of the lens, if the lens is *accurately* placed.

Place the other block near the other end of the paper in such position that the vertical part of the wire it carries shall be near the principal axis of the lens. Keep the eye 20 or 30 cm. distant from this part of the wire, on a level with the centre of the lens and in line with the centre of the lens and vertical part of the wire. Look at this part of the wire so as to see it *distinctly*, and note whether you can see at the same time, near the wire, the image of the pencil-mark on the farther block. If so, find out by moving the eye to the right or left, as in Exercise 23, whether this image is more or less distant from the eye than the vertical wire is. Then move the block carrying the wire into such a position that the image and the wire seem to keep close together when the eye is moved a considerable distance to the right or left. When this adjustment is made, put a dot on the paper just beneath the vertical wire and mark this dot 3. It represents the image of object-point No. 3.

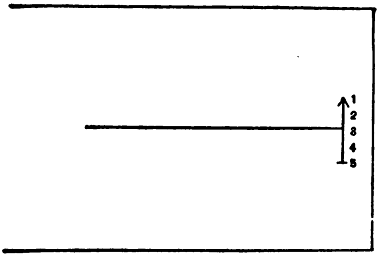

Fig. 30.

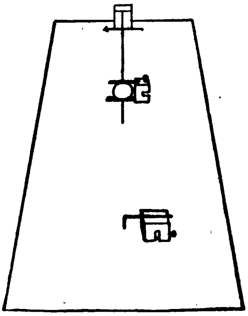

Fig. 31.

Find in a similar manner the image-points 1, 2, 4, 5, corresponding to the object-points 1, 2, 4, 5. The experimenter must take care not to let any idea he may have as to the position where an image-point ought to be affect his judgment in deciding where it is.

After all the five image-points are found, connect them, No. 1 to No. 2, No. 2 to No. 3, etc., by means of straight lines, thus getting a rough representation of the whole image.

Draw from each object-point toward the corresponding image-point a straight line as long as the ruler (No. 23), and note the point where these lines cross each other.

EXERCISE 25.

VIRTUAL IMAGE FORMED BY A LENS.

Apparatus: The same as for the preceding Exercise, except that the sheet of paper need not be more than one half as long, and that the arrow upon it should be 4 cm. long and about 20 cm. distant from one end.

Place the lens between the arrow and the nearer end of the sheet of paper, at a distance from the arrow equal to about two-thirds of its focal length, and in such a position that its principal axis extends over the middle point of the arrow. Place the small block (No. 25) with vertical pencil-mark pointing straight down at the middle point, No. 3, of the arrow. Turn the vertical part of the wire on the other block so that it will point up instead of down, and place this block some distance behind the other one.

Holding the eye 20 or 30 cm. from the lens, look *through* the lens at the image of the vertical pencil-mark, and at the same time *over* the lens at the vertical part of the wire. Bring the wire into line with the image, and then by the usual test find which of them is the more distant. Move the wire back and forth until it coincides in position with the image. Then mark with a figure 3 the point just under the vertical part of the wire. This represents the image of object-point No. 3.

In a similar manner locate the images of points 1, 2, 4, and 5.

Connect the image-points by straight lines, from 1 to 2, from 2 to 3, etc., thus forming an image of the arrow.

Draw a straight line from each image-point to its corresponding object-point, and note where these lines will cross each other if continued.

SECOND PART.

MECHANICS.

EXERCISE 26.

BREAKING-STRENGTH OF A WIRE.

Apparatus: Several pieces of spring-brass wire, No. 27 of Brown and Sharpe guage, each about 1 m. long. Articles 50, 51, 52, 53, 54 from the list at the back of the book.

The wooden cylinder No. 53 is fastened upright on the top of the table (see Fig. 32), and a tack is driven half-way into the table or into the cylinder near the base.

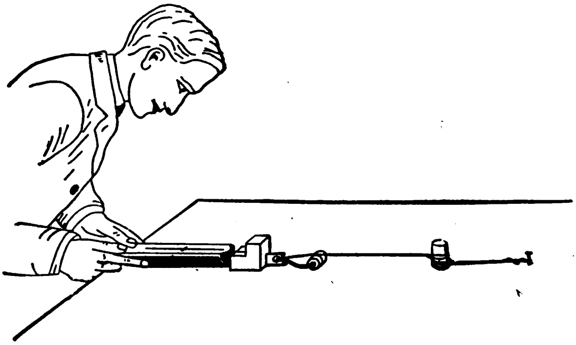

FIG. 32.

Take one of the pieces of wire and fasten one end securely to the tack and the other end to the bar of the balance, where the hook is attached. The sharp bends made in the wire at the points of fastening weaken it, and care must be taken to relieve these points in part from the pull that is to be applied to the wire. Therefore wind the wire at least three times around the upright cylinder and an equal number of times around the other wooden cylinder, which is slipped on the hook of the balance, taking care to avoid sharp kinks and making the turns upon each cylinder lie close together without overlapping.

Now, holding one foot well back, pull steadily with the spring-balance, gradually increasing the force, looking *vertically* down upon the index all the time (see Fig. 32), and taking care to avoid friction within the balance. Note the position of the index when the wire breaks, which it will do very suddenly at the last.*

Repeat the experiment a number of times, using each time a new piece of wire.

Take the average of the readings† made at the several breakings as the true strength of the wire, rejecting, however, any trials, if there are such, in which the wire breaks at either fastening.

Measure the diameter of an unbroken piece of the wire in thousandths of a centimeter, by means of the screw-calipers, and calculate the area of its cross-section as a fraction of a square centimeter.

Calculate the number of kilograms of force that would be required to break a rod of brass 1 sq. cm. in cross-section, if it were of the same quality and conditions as the brass of the wire.

EXERCISE 27.

COMPARISON OF WIRES IN BREAKING TESTS.

Apparatus: Two pieces of spring-brass wire just like that used in the preceding Exercise and two pieces of annealed soft iron wire of the same diameter, and of about the same length, as the brass wire. A candle. Other apparatus as in the preceding Exercise. The lengths of the guards used on the bar of the balance should vary with the strength of the wire used.

BRASS WIRE. — Measure the diameter of a piece of the brass wire. Light the candle and hold one end of the wire in the flame‡ for a few seconds. Wipe off the coating of soot deposited by the flame, and measure the diameter of the wire again to make sure it has not been made smaller by the flame. Now hold the two ends of the wire across each other, pinching each about 1 cm. from the tip, and try to bend one by means of the other. Which is the stiffer?

---

* If the wooden guard (No. 51) on the *bar* of the balance is not used, care must be taken to avoid injury to the hands from the recoiling hook of the balance when the wire breaks.

† When a spring-balance, graduated for use in the vertical position, is placed unstrained in the horizontal position, the index rests behind the zero-mark. The force required to bring the index out to the zero-mark when the balance is in this position can be found with sufficient accuracy by means of another much more sensive spring-balance, or by attaching to the hook one end of a string reaching over a pulley and bearing a known weight at the other end. This force is to be added to the actual readings of the balance in order to find the true force exerted by it in the horizontal position. (See Exercise 12.)

‡ A very hot flame like that of a Bunsen burner will melt the wire.

Now attach one of the brass wires to the balance and to the upright cylinder, precisely as in the preceding Exercise, and before breaking heat the wire, by means of a match-flame, at a point midway between the balance and the post. Then pull and note the force required to break the wire.

Note whether the wire broke at the point that had been heated. Measure the diameter at the point of breaking and see whether it is the same as before breaking. Test the stiffness of one of the broken ends, comparing it with an end that has just been heated, and see whether the breaking pull has increased or decreased the stiffness of the wire.

If satisfactory experiments have been made with one piece of brass wire, the other need not be used.

IRON WIRE. — Measure the diameter of the iron wire before breaking.

Note the force required to break this wire.

Measure the diameter of the iron wire at one of the broken ends.

QUESTIONS. — Does heating (or "annealing") spring-brass wire increase or decrease its stiffness?

Does it increase or decrease its strength?

Does annealed brass wire stretch perceptibly before breaking?

Does the breaking pull increase or decrease the stiffness of the annealed part of the wire?

Is the particular piece of soft iron wire used stronger or weaker than the annealed brass wire of the same diameter? Is it stronger or weaker than the unannealed spring-brass, as tested in the preceding Exercise?

How great is the *elongation* of the iron; that is, the ratio of the increase of length to the original length? (The increase of length is to be calculated from the decrease of diameter caused by the breaking pull.)

EXERCISE 28.

ELASTICITY : STRETCHING.

Apparatus: A piece of No. 27 spring-brass wire 4 m. or more long, soldered at one end to a screw driven into a table-top or other convenient fixed object, and having, about 10 cm. from the free end, a piece of paper fastened crosswise, as in Fig. 33, with sealing-wax. (This paper serves as an index, or marker, and is best put on after the wire is attached to the balance.)

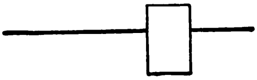

FIG. 33.

Nos. 2 and 50, and a short focus-lens to be used as a magnifying-glass.

Attach the free end of the wire securely to the hook of the balance. Let one experimenter draw the wire straight by means of the balance, while another measures its length from the screw to the marker on the wire. (This measurement need not be made with extreme care, as an error of a few millimeters would make practically no difference in the final result of the Exercise.)

Lay the meter-rod under the marker, parallel to the wire, at such a height that one end of the marker touches the rod, and then, making sure that the rod does not move, note with the magnifying-lens the change in position of the edge of the marker, when the pull on the balance is increased to 1, 2, and 3 kgm. in succession, beyond the first straightening pull, coming back after each increase to this original pull to see whether the marker returns, as it should, to its original position.

The wire being rigidly fastened to the screw at one end, the movement of the marker shows the increase in length of that part of the wire which lies between the screw and the marker.

Record thus:

$p =$ strengthening pull $=$ . . . . . . kgm.

	$F =$ increase of force.	$l =$ increase of length.	$F \div l$
From p to $p + 1$ kgm.	$= 1$ kgm.	. . . . . .	. . . .
" " " " $+ 2$ "	$= 2$ "	. . . . . .	. . . .
" " " " $+ 3$ "	$= 3$ "	. . . . . .	. . . .

Find the mean value of Fl, and then knowing L, the length of the stretched part of the wire, and the area of cross-section, S, of the wire (see Exercise 26), calculate *Young's modulus* for this wire by means of the formula

$$Y.\,M. = \frac{F}{S} \div \frac{l}{L} = \frac{F \times L}{S \times l}.$$

The tests thus far described in this Exercise are not intended to exceed the elastic limit of the wire; that is, the wire is not expected to show any permanent increase of length as a result of the stretching. It would be well to continue the experiment by increasing the stretching force, 1 kgm. or less at a time, until it becomes great enough to produce permanent stretching. The ratio of the force at this stage to that required to *break* the wire (see Exercise 26) should then be noted.

After the wire has become permanently stretched it should not be used again.

EXERCISE 29.

3 th.

ELASTICITY: BENDING. EFFECT OF VARYING LOAD.

Apparatus: Articles 55A, 56, 57, 58, 59, 60 (100 to 400 gm.).

Mark lightly two points on the rod 100 cm. apart and mark the point midway between them. Support the rod on two of the wooden prisms placed 100 cm. apart (see Fig. 34), each prism being just under one of the marks on the rod, the central mark on the rod being just over one of the holes in the table-top.

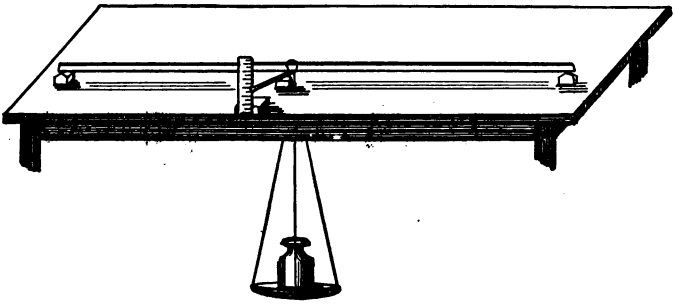

FIG. 34.

Suspend the scale-pan from the middle of the rod, so that it may hang beneath the table-top, taking care to prevent the suspending string from touching the table.

Near one end of the thin slip of wood (No. 57) make a light cross-mark, and call this mark *1*. Make a similar mark 5 cm. from the first, and call this second mark *2*. Make a third similar mark 25 cm. from mark 2, and call this last mark *3*. The slip of wood is to be used as an index.

Place the third prism parallel to the rod and opposite the middle, and rest the index on the top ridge of the prism as a fulcrum, the mark 2 being exactly over this ridge and mark 1 being exactly under the nearer edge of the rod. Place the upright scale alongside the index, so that the face of the scale, upon which the divisions are marked, shall be just as distant from the rod as the mark 3 is.

It is now evident that, if the centre of the rod is pushed down any distance, the height of the point at which the index passes the face of the scale will be raised five times this distance.

Everything being carefully adjusted,* read the point on the scale where the upper edge of the index passes it, and record this reading in the third column of a table, made like that below, under the heading "Readings without Load."

Then place 100 gm. in the pan, watching the apparatus to see that nothing is deranged in this operation; take the reading and record it in the column headed "Readings with load," placing alongside in the column headed "Load" the number 100. Then carefully remove the weight and make another reading, to be recorded in the column "without load."†

Then put 200 gm. in the pan, read and record as before, and make another reading "without load." Then take 300 gm. and 400 gm. in turn.

In this way the observations are made and recorded in the first three columns of the table. The other columns explain themselves. The last column, which shows how much the rod bends per gram in each case, should be particularly noted.

---

* This rod is sometimes warped so that it will not rest fairly on the prisms at the ends. In this case one end of one of these prisms should be elevated as much as may be necessary to give a good bearing at both ends of the rod. Thin, flat, slips of cardboard serve very well for making this adjustment.

Sometimes a rod has such a bend that its centre is considerably higher than the fulcrum, and the index does not touch the front *edge* of the rod. In such a case the fulcrum should be raised by means of the cardboard slips.

† Slight differences may be expected in the "readings without load," but these differences should not be as great as 0.1 cm.

Load.	Readings with load.	Readings without load.	Mean.	Rise of pointer on scale.	Deflection of rod.	Deflection per gm.
gm.	cm.	cm.	cm.	cm.	cm.	cm.
100	3.40	3.00 3.00	3.00	0.40 ÷ 5 =	0.080	0.00080
200	3.75	2.96	2.08	0.77 . .	0.154	0.00077
....	....	....	....	....	....	....
....	....	....	....	....	....	....
					Mean	....

EXERCISE 30.

ELASTICITY: BENDING. EFFECT OF VARYING DIMENSIONS.

Apparatus: As in Exercise 28, with the addition of No. 55B and the remaining weights of No. 60.

Three conditions are to be tried, which will be called the Second, Third, and Fourth Cases. Exercise 28 is regarded the First Case.

SECOND CASE.—Use the narrow rod with supports 50 cm. apart. Use first 1000 gm., and then double this load, following the same method of procedure and record as in Exercise 28.

THIRD CASE.—Use the broad rod on its broad side with supports 100 cm. apart. Use 400 gm., and then double this load.

FOURTH CASE.—Use the broad rod on edge with supports 100 cm. apart. Use 1000 gm., and then double this load.

Find for each case the deflection per gram.

EXERCISE 31.

ELASTICITY: TWISTING.

Apparatus: Articles 7 (two), 50 (two), 61, 62, 63. Strings for attaching the balances to the cross-bars.

FIRST CASE.—Fasten the small rod to the horizontal bar over the laboratory table in a vertical position, so that the top of a cross-bar (shown as a disk in Fig. 35) will be 80 cm. beneath the fastening, the brad beneath the cross-bar entering a small hole made to receive it in the table, the cross-bar clearing the table-top by two or three millimeters. Adjust and fasten the graduated arc upon the table, so that the centre of the circle of which it makes a part shall coincide with the centre of the brad at the bottom of the rod, the 0° at one end of the scale being just beneath a vertical index-mark made on one end of the cross-bar.

Attach one of the small spring-balances to each peg upon the cross-bar by means of a string of convenient length, and pull in opposite directions upon these balances, keeping the line of pull at right angles with the cross-bar at each end, and applying to each balance a force of 50 gm. Observe and record the number of degrees* moved over by the vertical index-mark on the end of the cross-bar, which will indicate the number of degrees of torsion produced by the forces applied. Note whether the index returns, as it should, to its original position when the pull ceases.

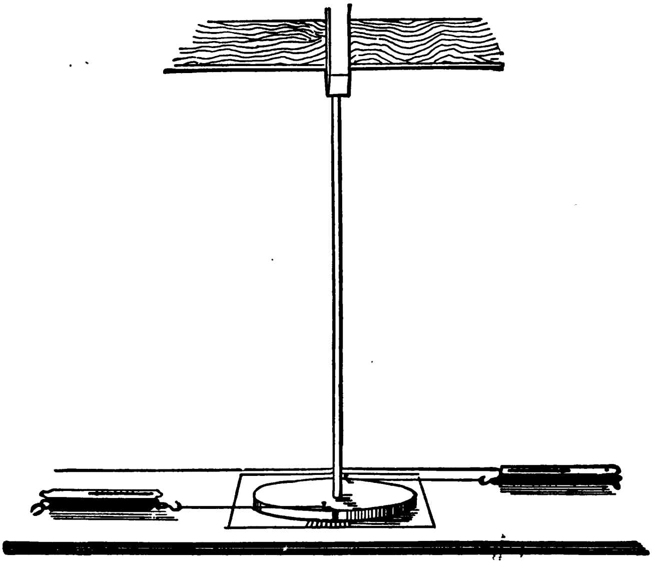

FIG. 35.

Then pull with a force of 100 gm. upon each balance, observe and record the amount of torsion. (After this and every other application of twisting force look to see whether the index returns to its initial position. If the rod is twisted too far, it will not entirely recover.)

Then apply 200 gm. to each balance, observing and recording as before.

---

* Read, if practicable, to one tenth of a degree.

Second Case. — Lower the horizontal supporting bar until a length of 30 cm. only remains between the fastening and the top of the cross-bar. Then proceed as in the First Case, using the same forces as before.

Third Case. — Replace the thin rod by the thick one, using 80 cm. as in the First Case. Apply forces of 500 and 1000 gm. in turn.

All the observations made in this Exercise should be recorded in a tabular form similar to that used in the two preceding Exercises. Thus for the

First Case.

Force at each balance.	Readings under stress.	Readings without stress.	Torsion per 1 gm. at each end.
		0°.0	
50 gm.	8°.2		0°.164
		0°.0	
100 "	....		....
		....	
150 "	....		....
		....	
		Mean =	....

EXERCISE 32.

SPECIFIC GRAVITY OF A LIQUID BY BALANCING COLUMNS.

Apparatus: Articles 64, 65, and 66. Water for one of the tumblers and a nearly saturated solution of sulphate of copper for the other.

Place the free ends of the glass tubes one in the water and the other in the sulphate of copper, and fix them in a vertical position against the upright (see Fig. 36). Observe and record the height to which each liquid rises in its tube by capillary action, the pinch-cock being open.

Applying the lips* to the open rubber tube at the top, draw out some of the air, thus raising the two liquids in their respective tubes. When the taller column reaches nearly to the top of the glass tube, pinch the rubber tube near the lips, and then close the pinch-cock.

---

* This use of the lips can be avoided by using a small air-pump. To prevent too sudden action of the pump a large bottle should be inserted between it and the upright tube.

Watch the columns to make sure that there is no falling of their surfaces, as there will be if the connections are not air-tight. (It is well to moisten the connections occasionally with a little glycerine to keep them air-tight.)

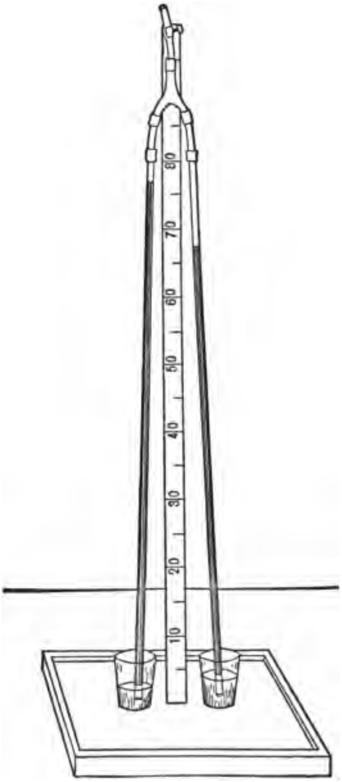

Fig. 36.

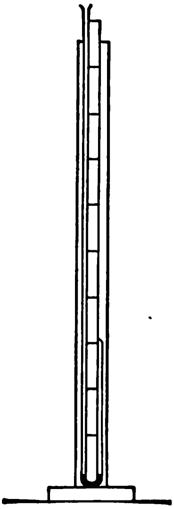

Fig. 37.

When assured that the columns are not sinking, measure carefully the height of each from the *present* level of the liquid surface in the corresponding tumbler.

Subtract from the height of each column as thus measured the height to which it was raised by capillary action at the beginning.

From the data now obtained find the specific gravity of the solution of sulphate of copper.

EXERCISE 33.

COMPRESSIBILITY OF AIR: BOYLE'S LAW.

Apparatus: No. 67, and No. 66 to support it. Sufficient mercury to fill at least the long arm of the tube. A barometer (No. 68).

Pour into the bent glass tube sufficient mercury to fill the bend and rise to the straight part in each arm. At first the mercury will stand a little higher in the long arm, but by tipping the tube and letting out out a little of the imprisoned air the level can be made the same in both arms, as in Fig. 37, or left only one or two millimeters higher in the long arm than in the other. This operation may well be performed before the tube is attached to its support.

Now measure the length of the imprisoned air-column, from the curved top of the mercury-surface to the curved top of the bore of the tube, taking care not to handle the short arm much, lest the warmth of the hand expand the air, and write the length thus found under the letter V[*] in a table like that here indicated.

V	P	$V \times P$
....	....	....
....	....	....
....	....	....
....	....	....

The pressure upon the air is now, if the mercury-level is the same in both arms, equal to that upon the unimprisoned air. It is as great as would be exerted by a column of mercury as tall as that in the barometer. Take, then, a reading of the barometer, and record this reading under the letter P[†] in the table. But if the level is a little higher in the long arm than in the short arm, write under P the height of the barometer column *plus* the excess of height in the long arm.

Pour in more mercury till the difference of level in the two arms is about 20 cm., then measure again the length of the confined air-column. Record this length under V, and record under P the barometric height *plus* the present difference of mercury-level in the arms of the tube.

---

[*] The *length* of the air-column is equal to *its volume*, if we take for our unit of volume in this experiment the space contained in unit length, 1 cm., of the tube. The bore of the tube is supposed to be of the same size throughout the short arm.

[†] It is common practice to measure pressure in terms of centimeters of depth of mercury.

Proceed in this way, by fairly uniform stages, measuring and recording at each stage, till the volume of the confined air-column is about one-half what it was at first.

Multiply each number under V by the corresponding number under P, and write the products in the column headed $V \times P$. An examination of this column will probably show a pretty close confirmation of *Boyle's* law.

EXERCISE 34.

DENSITY OF AIR.

Apparatus: Nos. 68, 69, 70 (supported by 66), 71, 72, and 73.

Set up the apparatus according to Fig. 38, after moistening with glycerine the junctions at which leakage might occur, and pour mercury into the U-tube till both arms are about half full.

Work the pump and draw air from the bottle until the difference of mercury-level in the arms of the U-tube gauge is as much as 70 cm., then pinch the rubber tube that leads from the pump very hard and watch the mercury in the gauge for a short time to see whether it is changing level. If it is changing, there is some leak which should be looked for and stopped. If there is no leak, read and record the difference of level in the arms of the mercury-gauge, and then immediately close the pinch-cock near the bottle, making it thoroughly tight.

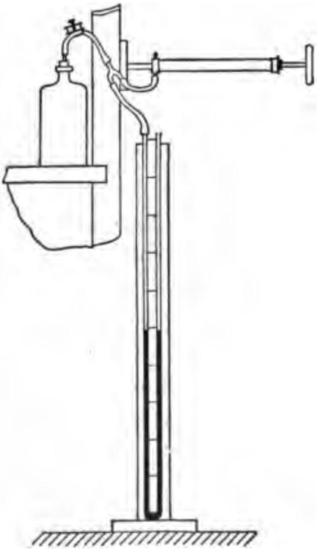

FIG. 38.

Disconnect the bottle, with the attached tube and pinch-cock, from the rest of the apparatus and place it on the platform balance, after making sure that this balance is in good condition. Weigh the bottle and attachments very carefully, to the nearest tenth of a gram if possible, and then, without removing the bottle from the balance, open the pinch-cock and let the air enter. Then weigh again, as carefully as before.

The difference of the two weights thus found is the weight of the air originally pumped out from the bottle. The reading of the mercury-gauge, already recorded, compared with the height of the barometric column, which should now be read, will show what fraction this was of the whole amount of air contained by the bottle when open to the atmosphere, and so the weight of all the air in the bottle can be found.

It is now only necessary to find the capacity of the bottle, in cu. cm., in order to be able to calculate the density* of the air. The capacity of the bottle may be found by finding how many grams of water it will hold.†

EXERCISE 35.

FOUR FORCES AT RIGHT ANGLES IN ONE PLANE.

Apparatus: Four spring-balances (No. 50). No 74 (without the cross-bar). Four beds (No. 75) for the balances. Hard-twisted cord capable of sustaining at least 10 kgm., but not over-bulky.

Using the balances carefully, and having the iron pegs set well down into the holes, so that the strings must be near the surface of the board, find by experiment a case of equilibrium, with one of the forces acting north, one south, one east, and one west, no two strings lying in the same line.

Record this case of equilibrium thus:

Hole.	Force.	Direction.	
....	....	....	Equilibrium.
....	....	....	
....	....	....	
....	....	....	

Find and record at least two other cases of equilibrium, varying the arrangements as much as practicable, but observing the conditions above mentioned.

---

* Unless this Exercise is performed with care and intelligence the results will be absurdly inaccurate. No balance available for elementary laboratory purposes is quite satisfactory for such weighing as that here described. Nevertheless, the Exercise, if carefully done, is instructive and profitable.

† It is well for the teacher to determine the capacity of the bottle once for all and mark it on a label, in order to save frequent wetting of the interior. Drying out bottles is a very tedious and thankless task.

Compare the magnitudes of the forces in each of these cases of equilibrium. Is there any fixed relation between the magnitude of the force north and that of the simultaneous force south? between that of the force east and that of the force west? between that of the force north and that of the force east? etc.

Calculate, in at least one of the cases of equilibrium, the moments of the various forces with respect to some one of the pegs used, and compare the sum of the positive moments with the sum of the negative moments. Do the same with respect to each of the other pegs used in this case of equilibrium, and with respect to one or two other points on the board. State carefully any general conclusion inferred from the Exercise. Has the Exercise anything to do with "couples"?

EXERCISE 36.

(For two or three students working together.)

COMPARISON OF MASSES BY ACCELERATION-TEST.

Apparatus: Nos. 76, 77, and 78. Lead scraps *ad libitum* for one of the carriages. A pinch-cock.

Test of the Rubber Tubes. — The Exercise requires these tubes to exert the same contractive force when equally stretched. After making sure that they are of equal length when unstretched, which can best be done by measuring them while they are hanging straight downward from the carriages, fasten them together with a pinch-cock at the free ends, as in Fig. 39, and then pull the two carriages away from each other until each tube is about twice as long as before stretching. They are now subject to the same force, and if the point of junction is midway between the carriages, that is, if the tubes have stretched equally, they require no further adjustment. If one tube has stretched less than the other, slit it open for a distance of fifteen or twenty centimeters and trim off a narrow piece along the edge of the slit, until this tube stretches just as much as the other. The tubes may now be separated. Hereafter they will, until their properties suffer some change, exert equal pulls when equally stretched.

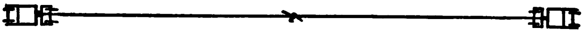

Fig. 39.

Balancing Friction. — The resistance due to friction is balanced, as nearly as may be, by making each carriage roll upon one of the planks which are placed side by side, so inclined that the carriage, once started very slowly down the incline, will barely continue in motion to the bottom.*

Friction being thus balanced by the slight pull of gravity down the incline, the elastic tubes when used will have to deal with inertia alone, so that the test may now proceed as if with frictionless carriages on a level surface.

THE ACCELERATION-TEST. — Load one carriage with the iron, as in Fig. 40, and the other with an unknown amount of lead scraps. Let one student hold each carriage at the top of its incline, the hind wheels against the upper cleat. Let another stretch the rubber tubes, each over the middle of its own plank, till the tip rests upon the cleats at the bottom. Let a third place himself by the side of the incline, to watch the progress of the carriages when released, and to stop them before they reach the bottom.

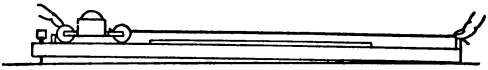

FIG. 40.

Let the experimenter No. 1 release both carriages at the same instant, for which purpose he will do well to hold them both with one hand, and let No. 3 watch sharply to see which carriage is ahead at that part of the incline where the tubes cease to pull. (It is well to have a pencil-mark drawn straight across both boards at this place.)

Then increase or decrease the load of lead as the case seems to require, and repeat the test and readjustment of load many times, very carefully at the last, until no difference can be detected in the time of arrival of the two carriages at the pencil-mark just mentioned.

THE WEIGHT-TEST.—Weigh the carriages with their loads, as finally adjusted in the acceleration-test, and thus see how accurate the work of that test has been.

---

* It is quite likely that the two carriages will require different inclinations, but with a good carriage on a good plank the inclination need not be greater than 1 in 50. The bearings of the carriages should be oiled; but if too much oil is used, it is likely to come into contact with the rubber tubes and spoil them.

EXPERIMENT.

(Preliminary to Exercise 37.)

Apparatus: Two pendulums — bullets suspended by threads — with suspensions of equal length, the longer the better. Wooden blocks to be struck by the pendulum-balls at any chosen points of their paths. A meter-rod.

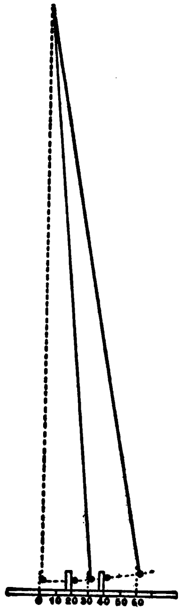

Fig. 41.

Suspend the pendulums so that there shall be about 4 cm. of clear space between the balls. Place the meter-rod between the balls, with its length at right angles with the line connecting the centres of the balls. Draw one of the balls to one side 60 cm., as measured on the rod, and the other ball in the same direction 30 cm., as in Fig. 41. Place the blocks so that each ball will strike after traveling one third of the horizontal distance to its lowest position. Release the balls at the same instant, and listen very attentively to decide whether they strike at the same instant.*

Let the balls be stopped in the same way after having traversed one half, two thirds, then the whole, of the distances to the lowest point. If time permits, the examination may be carried beyond the lowest points of the arcs.

---

* The method just described is, owing to the limited power of the ear to note small intervals of time, not very accurate. It serves, however, to indicate methods which would be accurate, and it is therefore given to relieve the teacher from the necessity of stating to his class entirely without proof the fact which he wishes to use. Another method, devised in its essentials by Mr. Schobinger, of the Harvard School, Chicago, will now be described. It is suited to individual experimentation rather than to lecture-room use. Suspend the two pendulums, made as nearly ischronous as practicable, some little distance apart — for instance, 60 cm. Then stick a tall pin or pocket-knife upright in the table just in line with the two balls, and about 60 cm. distant from the nearer ball, so that when the eye of the observer is placed at the top of the pin or knife the nearer ball hides the other. Then let the two balls be pulled to one side, with such displacements that the nearer ball still hides the other from the observer placed as before. Let the balls be released at the same instant. If the nearer continues to hide the other during one whole swing, it is evident that the velocities must have nearly the same ratio throughout the swing.

If in all cases here suggested, and any others that may be tried, the blows given by the two balls come so nearly together that no interval between them can be detected, it may fairly be concluded that the ratio of the velocities of the balls at any instant — when each is passing through its lowest point, for instance — is nearly, if not quite, equal to the ratio of the horizontal components of the paths in which the balls travel. Conclusions for the cases tried must not be extended to cases in which the arcs are much larger parts of circles.

EXERCISE 37.

ACTION AND REACTION: ELASTIC COLLISION.

(For two or three students working together.)

Apparatus: All the articles of No. 79, the beveled suspension-board being attached to the highest * convenient support, the wires in slots 1 and 2 (Fig. 42), so that the suspended balls just graze each other, with their centres about 4 cm. above the graduated rod.

Place the detents about 50 cm. apart, and so adjust the base-board that both of the suspension-wires shall lie in the line of sight through the middle of the slots of the uprights (see Fig. 43), the point of contact of the balls being exactly over the middle point, the 50 cm. mark, of the base-board.†

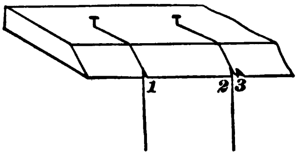

FIG. 42.

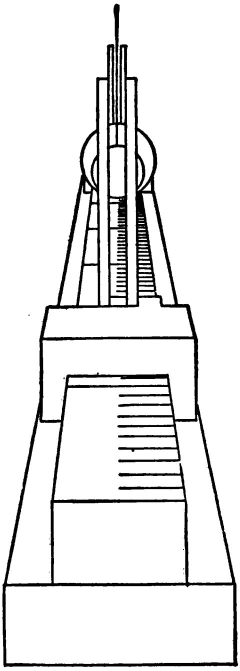

FIG. 43.

The larger ball will be called A, the smaller B.

---

* The distances mentioned in this Exercise are appropriate to a suspension 2 m. in length.

† The adjustment of the base-board is very important, and there should be some means of fastening it in place after the adjustment is made.

The mass of the larger ball will be called m_a; the mass of the smaller ball, m_b; the distance moved by *A* before collision will be called D_a; the distance moved by *B* before collision, D_b; the distance moved by *A* after collision, d_a; the distance moved by *B* after collision, d_b; movements from small to large on the scale will be called $+$; movements from large to small on the scale, $-$.

The movements of each ball are to be determined by watching that side of each which is turned toward the other ball.

First Case.—Make $D_a = 0$; that is, leave *A* in its position of rest. Make $D_b = 30$ cm.; that is, place the detent in such a position that when *B* is released it will have to move 30 cm., measured horizontally, before it can strike *A*.

After making sure that *A* is at rest, as nearly as may be, release *B* suddenly but quietly, and let it swing against *A*. Then note d_a, the distance *A* swings as a result of the collision, and d_b, the distance *B* rebounds after the collision.

Repeat this experiment several times, and finally, having decided upon the values of d_a and d_b, see whether this equation holds true.*

$$\overset{\text{Representing momentum before collision.}}{(m_a \times D_a) + (m_b \times D_b)} = \overset{\text{Representing momentum after collision.}}{(m_a \times d_a) + (m_b \times d_b)}$$

Second Case.—Make $D_a = 15$ cm. and $D_b = 0$. Determine d_a (the onward movement of *A* after the collision) and d_b by several trials, and then compare the total momentum before collision with the total momentum after collision, as in the preceding case.

In considering the result of this Exercise it should be borne in mind that a pendulum does suffer some slight loss of motion from the resistance of the air. As the momentum just before collision is estimated from the length of swing preceding contact, and the momentum just after collision from the swing following contact, it is evident that the former estimate will be a little larger, and the latter a little smaller, than it should be. A rough estimate of the error caused in this way may be obtained by studying the rate of decrease of the pendulum-swings.

---

* No account is here taken of the mass of the suspending wires. If it seems worth while to consider them, one half the mass of its own suspending wire may be added to the mass of each ball. One half, because the upper end of the wire is at rest, while the lower end moves as fast as the ball.

EXERCISE 38.

ELASTIC COLLISION CONTINUED; INELASTIC COLLISION.

This Exercise is a continuation of Exercise 37. It requires the same apparatus, with the addition of a small quantity of putty. The Cases of the two Exercises are numbered consecutively.

Third Case. — Make $D_a = 15$ cm. and $D_b = 15$ cm. Release both the balls *at the same instant.* (This must be done by one person. It is well to attach a string to the upright of each detent, as in Fig. 44, pass the middle of the string through a hole or screw-eye near the centre of the base-board, and when all is ready pull suddenly upon this part of the string, taking care not to derange the base-board.)

Determine d_a and d_b by several trials, and then compare the total momentum before collision with the total momentum after collision, as in the preceding Cases.

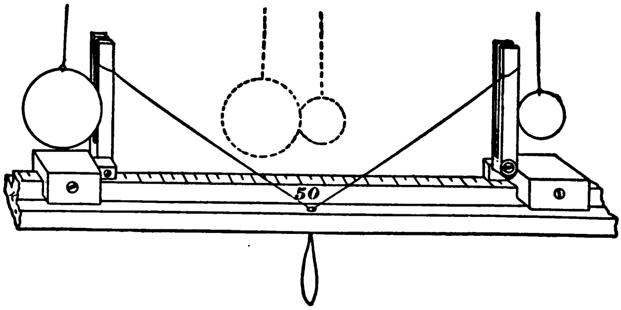

Fig. 44.

Fourth Case. — Let the suspending wires hang in slots 1 and 3 (Fig. 42). Put around the smaller ball a belt of putty about 1 cm. wide and 0.3 cm. thick, so that this belt will just touch the large ball when both are hanging at rest (Fig. 45). (The object of the putty is to destroy the elasticity of the collision, in order that the conditions of the momentum-test in this Case may be very different from those of the other cases. It will do little harm if the balls stick together at collision, though this may be prevented by covering the putty with thin paper at the point of contact.)

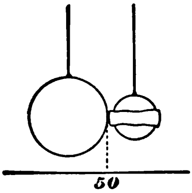

Fig. 45.

Make $D_a = 30$ cm. and $D_b = 0$ cm. Determine d_a and d_b by several trials, and then apply to the momentum-test as before, taking for m_b the mass of the ball *B* and its belt of putty.

HEAT.

EXERCISE 39.

TESTING A MERCURY-THERMOMETER.

Apparatus: Nos. 68, 80, 81, 82, and 83. Snow or ice. A short rubber tube and a pinch-cock. A rubber band to close the joint at the base of the cover of the boiler.

Examine the thermometer, holding it all the time bulb downward, to see whether any mercury has separated from the column and lodged at the top of the stem. If any is so lodged, it can probably be freed by grasping the thermometer near the middle of the stem (bulb outward) and swinging it rapidly back and forth, the arm being held at full length downward.

To test the freezing-point: Break the ice into fine pieces, the finer the better, and fill the dipper with it. Add only enough water to fill the space between the lumps of ice. Thrust the bulb of the thermometer down into the middle of the cup until the point marked 0° is only 1 or 2 mm. above the surface of the water. Give the mercury-column time to descend as far as it will, and then record the reading. (If its shortest divisions are a millimeter or more in length, try to read to tenths of these divisions. Place the eye in such a position that a straight line drawn from its centre would strike the thermometer at right angles at the top of the mercury-column.)

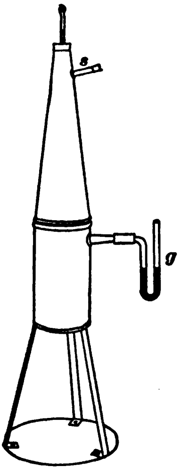

FIG. 46.

To test the boiling-point: Fill the boiler (Fig. 46) with water to the depth of 3 or 4 cm., put on the conical top, pressing it carefully down into place, attach the small mercury pressure-gauge, and thrust the bulb and the stem of the thermometer down through the perforated stopper until the point marked 100° is not more than 2 or 3 mm. above the top.

Boil* the water and keep it boiling, the steam escaping from the side tube near the top of the cone, until the mercury-column rises as far as it will, and then record the reading. (The flame of the burner beneath the boiler should not be allowed to flare out much beyond the bottom, lest the current of hot gases rising from it should overheat the mercury-gauge and the upper part of the vessel.)

Record the reading of the barometer.

To test the effect of increased pressure† *upon the boiling temperature:* Close the steam-outlet by means of a short rubber tube and a pinch-cock, or a tight stopper, the flame still burning, and watch the thermometer and the pressure-gauge. If the apparatus is properly closed, the gauge will very soon indicate a steam-pressure 4 or 5 cm. of mercury greater than the atmospheric pressure. The cover must be pushed in *hard* to prevent this pressure from lifting it. If there is too much leakage around the base of the cover, close the joint there by means of a rubber band. When everything is satisfactory, record both the rise of temperature and the rise of pressure.

This experiment, if successful, will be of service in estimating the error of the boiling-point. The true boiling-point error of the thermometer examined is obtained by finding what its reading would be in steam at a pressure of 76 cm. and subtracting 100° from this reading.

To test the effect of leaving the stem of the thermometer exposed to the air while the bulb is heated: Give the steam free escape once more and then, after noting the reading again, draw the thermometer up through the stopper until only the bulb and a few degrees of the stem are exposed to the steam. Watch the effect upon the reading as the stem cools.

Finally, if time permits, test the freezing-point again, taking care, as before, to have the snow or ice reach to the bottom of the dipper. It is not sufficient to have snow or ice floating in the water.

---

* To save time, it is well to begin heating the water before making the freezing-point test.

† The introduction of the pressure-gauge into this exercise is due to a suggestion from Mr. Rollins, formerly of the Newton High School. He had devised and used a more elaborate apparatus than that here described.

EXERCISE 40.

LINEAR EXPANSION OF A SOLID.

Apparatus: Nos. 80 (without the gauge), 82, 83, 84, 85, 86. A barometer. A meter-rod. A rubber tube 30 cm. long, to carry steam from the boiler to the sheet-iron tube; another, 15 cm. long, to carry the steam and water from the same tube (see Fig. 47). A small tumbler to catch the water thus drained off. (It is better not to place this tumbler on the wooden rack. Steam or water coming from it might wet some part of the rack and cause a swelling, in or near the back-post, that would seriously affect the position of the index. A similar, though less, danger threatens if much water or steam escapes from the other end of the sheet-iron tube.)

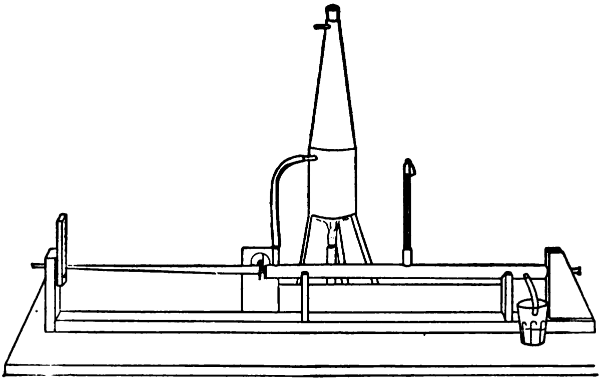

FIG. 47.

Fill the boiler to a depth of 3 cm. with water and place the lighted Bunsen burner beneath it, all outlets being closed except the lower side-tube.

Raise the long arm of the index and place the sheet-iron tube, the brass rod within it, in position on the rack, the untipped end of the rod resting against the screw back-stop, and then gently lower the index until the short arm bears against the sharp tip fastened to the rod.

Attach the 20-cm. rubber tube to the inlet-tube of the sheet-iron tube, making no connection as yet with the boiler; turn the cylinder in its bed till the inlet-tube rests against a firm support; attach the outlet rubber tube, leading to the tumbler; put the thermometer-bulb through the middle side-opening into the steam-cylinder alongside the rod, as in Fig. 47.

Measure and record the length of the brass rod, not including the sharp tip. This measurement need not be made with great care, as an error of 2 or 3 mm. here would make very little difference with the final result.

Measure, with about the same care, and record the length of the long arm of the index, from the centre of the pivot to the vertical scale.

Measure with much care and accuracy the short arm of the index, from the centre of the pivot to the point of the sharp tip. To do this push up the thin brass sleeve on the vertical arm of the index (see Fig. 48) until its upper edge touches the tip; then measure carefully the distance from the *base-board* of the rack to the top edge of the sleeve. Lift the horizontal arm and turn it back till it lies upon the sheet-iron cylinder, then measure carefully the distance from the base-board to the same edge of the sleeve, which is now the lower edge, the short arm of the index now extending upward, as indicated by the dotted lines in Fig. 48. One half the difference between these two measurements is the effective length of the short arm of the lever.

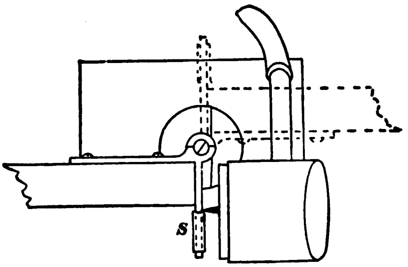

Fig. 48.

Read the thermometer, then remove it, and put a stopper in its place. There is no further use for the thermometer, as the higher temperature, that of the steam, can be found better from the barometric pressure. (See Exercise 39.)

Make sure that the brass rod still rests against the back-stop screw, then read, as accurately as you can, the position of the index, upper or lower edge according to convenience, upon the vertical scale.

By this time a good flow of steam should be coming from the boiler. Slip the end of the inlet rubber tube over the vent of the boiler and let the steam take its course through the tube on the rack. See that there is a free escape of steam from the other end of this tube.

Watch the index until it ceases to rise along the vertical scale, then read its position as carefully as before.

From the difference of the first and last readings upon the vertical scale we can, making use of the ratio of the index-arms, calculate the increase of length which the rise of temperature has produced in the rod.

From the data obtained is to be calculated the *coefficient of expansion of brass for 1 Centigrade degree*, that is, the fraction of itself by which the length of a bar of brass is increased when its temperature is raised 1 Centigrade degree. The calclation will assume that the expansion is equally great for each and every degree of the rise of temperature. This is not quite true. The quantity which the calculation gives is the average, or mean, value of the coefficient between the limits of temperature used.

Alternative Method.

Instead of the lever-index described in this Exercise, a micrometer-screw, similar in principle to that used in Exercise 26 for measuring the diameter of the wire, may be used for measuring the expansion of the rod. The delicacy and accuracy of this device can be increased by using an electric sounder to show when contact between rod and micrometer-screw occurs.

EXERCISE 41.

INCREASE OF PRESSURE OF A GAS HEATED AT CONSTANT VOLUME.

Apparatus: Nos. 80 (without the gauge), 83, 85, 86 (with the index put on in such a way that the long arm points in the usual way, while the short arm points upward, the pivot-screw being driven in so hard as to hold the index securely in any position which may be given it; see Fig. 49), 87, and 88. A meter-rod, a barometer, cork-stoppers and rubber connecting tubes, a quantity of snow or pounded ice.

In handling the tube that contains the dry air and the mercury keep the sealed branch nearly horizontal, do not lower the other branch enough to let any mercury flow out, and avoid shocks lest the mercury-column be broken so as to include bubbles of air.

Fill the boiler with water to the depth of several centimeters, put on the top, close all the openings except the lowest, and place the flame beneath. Lift and shake the boiler occasionally during the exercise, to find whether it is in danger of getting dry.

Measure the distance from the rubber tube attached to the dry-air tube to the sealed end of the bore of the latter tube. (If the sealed end of the bore *tapers*, do not measure to the extreme tip, but, as well as you can, to the spot where the bore would end if it stopped without tapering but had the same total volume as now.)

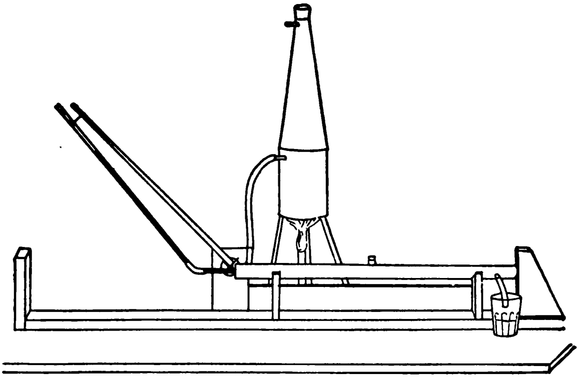

FIG. 49.

Push the sealed end through a short stopper into the cooling-tray (Fig. 50), and cover the whole length of the imprisoned air-column with snow, or with water kept at 0° C. by means of pounded ice. Support the outer glass tube in such a way that the two ends of the mercury-column shall be at the same level, pulling the sealed tube out through the stopper till the inner end of the mercury-column is just visible. Leave the tube in this condition for a few minutes, till contraction of the air-column has ceased; then measure the distance from the rubber tube to the inner end of the mercury-column.

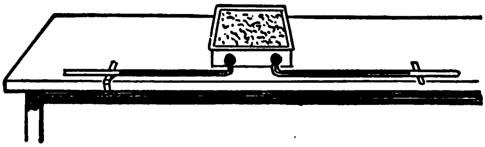

FIG. 50.

The difference between the two measurements now recorded is to be taken as the length of the imprisoned air-column at 0° C. under atmospheric pressure.

The barometer-reading should now be noted.

Close the rear end of the heating-tube on the rack, and fit the other end with a short cork-stopper, perforated to admit the sealed end of the air-tube. Take the latter tube from the cooling tray, and push the sealed end through this stopper till the whole length of the air-column disappears. Attach the outer glass branch loosely but securely to the long arm of the index, which now turns stiffly on its pivot, and set this index in such a position as to raise the outer end of the glass tube some 40 cm. above the horizontal air-tube.

Lead steam from the boiler to the heating-tube on the rack. As soon as a good flow is established, draw the air-tube carefully through the perforated stopper, in which it should fit snugly, till the distance from this stopper to the rubber tube is just equal to the distance that was measured from the inner end of the mercury-column to the rubber tube when the air-tube was in the cooling tray.

Without allowing the distance just measured to change, raise or lower the outer glass branch till the pressure is such as to hold the inner end of the mercury-column just at the outer end of the cork stopper, thus making the length of the imprisoned air-column just* what it was at 0° C. under atmospheric pressure.

After making sure that expansion of the imprisoned air has ceased, measure the difference in height of the two ends of the mercury-column.† This difference represents the increase of pressure required to keep the volume of the air the same at the temperature of steam as at the temperature of melting ice.

Calculate a_1, the *coefficient of expansion of pressure with constant volume*, thus:

$$a_1 = (p_t - p_0) \div p_0(t - 0),$$

where $p_0 =$ pressure (atmospheric) upon the air at 0° C.,
$p_t =$ total pressure upon the air at steam temperature,
$t =$ temperature of steam (found from the barometer-reading).

---

* The expansion of the *glass*, very small compared with that of air, is neglected in Exercises 41 and 42.

† Lack of level in the table-top or the base of the rack may cause considerable error in this measurement.

EXERCISE 42.

INCREASE OF VOLUME IN A GAS HEATED UNDER CONSTANT PRESSURE.

Apparatus: The same as in the preceding Exercise.

Proceed exactly as in the preceding Exercise, until the steam begins to flow through the heating-tube. Then put and keep the two ends of the mercury-column at the same level, the inner end being kept just at the outer surface of the cork-stopper, and, when expansion ceases, measure the distance from this end to the rubber tube.

It is evident that when this measurement is made, the air is under the same pressure as when it was in the cooling tray. The increase of length of the air-column, representing its increase of volume, is found from the measurements now recorded.

Calculate a_2, the *coefficient of expansion of volume with constant pressure*, thus:

$$a_2 = (l_t - l_0) \div l_0(t - 0),$$

where $l_0 =$ the length of air-column at 0° C.,
$l_t =$ " " " " " the steam temperature.
$t =$ " temperature of steam.

EXERCISE 43.

SPECIFIC HEAT OF SHOT.

Apparatus: Nos. 71, 80 (without the conical top or the gauge), 81, 83, 89, 90. A piece of pasteboard to cover the top of the dipper.

Half-fill the boiler with water and place the flame beneath it.

Adjust the balance and weigh the calorimeter.

Weigh out in the calorimeter about 500 gm. of shot, pour* them into the copper heating-dipper, place this dipper in the boiler, the bottom in the water, and cover it with the pasteboard. See Fig. 51.

Weigh out in the calorimeter about 100 gm. of water, already cooled to a temperature 7 or 8 degrees below the temperature of the room.

---

* It is well to *practice* pouring the shot from the dipper into the calorimeter in order to acquire the art of doing it quickly and surely when there is need.

Push the bulb of the thermometer through a hole in the pasteboard cover down into the shot, and note the rise of temperature, stirring the shot frequently with the thermometer. When the mercury has finally ceased to rise, withdraw the thermometer.

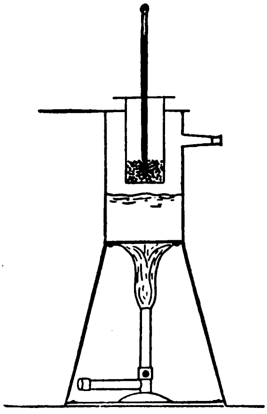

FIG. 51.

After the thermometer has cooled 40 or 50 degrees in the air, place the bulb in the water within the calorimeter, stir this water very thoroughly and take its temperature with care, reading to 0.1 of a degree. Meanwhile the shot should be occasionally stirred with a pencil or other convenient instrument.

Remove the thermometer, take the dipper, still covered, from the boiler, pour the shot quickly into the calorimeter, put in the thermometer and stir the water and shot vigorously* and thoroughly for about 10 seconds. Continue the stirring gently, note the temperature of the water frequently, and when it has ceased to rise read and record it.

In calculating the specific heat of shot from the observations of this Exercise it is well to add 0°.5 to the highest reading of the thermometer in the shot, because the greater part of the stem was exposed to the air.

It may be assumed that the whole calorimeter rises in temperature with the water it contains when the shot are poured in. The "thermal capacity" or "water-equivalent" of the calorimeter, if it is of brass, may be found with sufficient accuracy by multiplying its weight by 0.1, that being, approximately, the specific heat of brass.

EXERCISE 44.

LATENT HEAT OF MELTING ICE.

Apparatus: Nos. 71, 80 (without the top), 82, 83, 89. About 150 gm. of ice in large clear lumps. (It is important to have the ice as dry as may be, when it is put into the water. If it is pounded fine long before being used, the melting, which is going on continually at the surface of each small lump in a room at the ordinary temperature, fills the spaces between with water, and serious error may result.) Placed in a canvas bag (No. 91) and struck smartly against any firm resisting surface, the large lumps may be quickly powdered when the ice is needed. They should be kept in some convenient vessel — a saucer, for instance — until the time comes.

---

* If the common paper-scale thermometer is grasped as near the bulb as possible, it may be used very vigorously as a stirrer, with little danger of breaking.

Half-fill the boiler with water, and place the flame beneath. Weigh the calorimeter. When the water in the boiler is near 50° C., pour about 200 gm. of it into the calorimeter, and weigh it with an accuracy of 0.5 gm.

Immediately transfer the lumps of ice to the bag, taking care not to *pour* them in lest water should go with them, and pound them fine. Stir the water in the calorimeter thoroughly, take its temperature, and then put into it about two thirds of the ice, avoiding the wetter portions. The weight of ice added need not be determined with accuracy at first, as it can be found by carefully weighing the vessel and its contents after the hurry is over.

Stir the water thoroughly, though not violently, with the thermometer, and record the temperature, as soon as all the ice is melted. If so much ice has been put in as to cool the water below 5° C., it is well to dip out the ice remaining unmelted at that temperature, taking as little water with it as possible.

Weigh the calorimeter and its contents, in order to find more exactly the weight of ice added.

Calculate the *latent heat of fusion* of ice, that is, the number of units of heat required to change 1 gm. of ice, taken at 0° C., into water at the same temperature. The thermal capacity of the calorimeter is to be taken into account in this and the following Exercise, as in the one preceding.

EXERCISE 45.

DETERMINATION OF THE DEW-POINT.

Apparatus: Nos. 82 and 89. Ice, or snow, and salt.

Pour a little water at the ordinary temperature into the cup, and into this put the bulb of the thermometer. Gradually cool this water by small additions of ice-water or ice, and finally of salt if necessary, watching the outside of the lower part of the cup after each addition, and continually stirring its contents. As soon as a mist begins to form on the bright surface near the bottom of the vessel, note the temperature, and cease adding ice.

It is likely that the temperature thus observed will be a little lower than necessary, a little below the true dew-point. Therefore reverse the process, making small additions of water, taken at the room temperature, until the mist begins to disappear. Then take the temperature again. This will probably be a little higher than the dew-point.

It is well to repeat the experiment. After one or two trials, the temperature found going down and that found coming up the scale should be pretty close together — not more than one or two degrees apart. The mean of the two may then be taken as the dew-point.

The experimenter must avoid breathing upon the outside of the vessel or holding any damp object near it, while looking for the mist to form.

If a thick layer of moisture forms upon the vessel before the reverse process is begun, it should be wiped off. A thin layer can be put on, when it is desired, by a mere breath.

The state of the weather and the out-of-door temperature should be noted in connection with this Exercise.

EXERCISE 46.

LATENT HEAT OF VAPORIZATION.

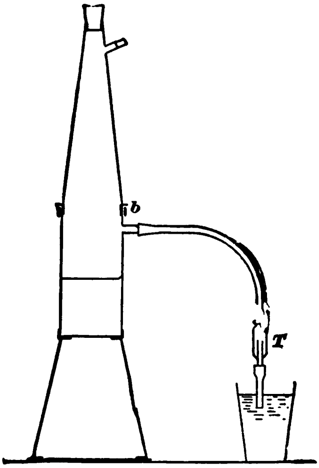

Fig. 52.

Apparatus: Nos. 71, 80, 82, 83, 89, and 92. Snow or ice. A board or sheet of pasteboard to serve as a shield between the lamp and the calorimeter; not shown in Fig. 52. A rubber band, *b*, to prevent leakage of boiler.

Fill the boiler to a depth of about 5 cm. with water, press down the cover with especial care, and adjust the band *b*, close the two apertures at the top, and attach the glass "trap," *T*, to the side-tube, as in Fig. 52. Place a Bunsen flame beneath the boiler.

Weigh the calorimeter, and then weigh in it with much care about

300 gm. of water, some fifteen degrees below the temperature of the room. See that the outside of the calorimeter is kept dry.

As soon as there is a strong flow of steam through the trap, put the shield in place, stir the cold water thoroughly, take its temperature, then dip the escape-tube of the trap about 2 cm. beneath its surface. If the boiler is reasonably tight and the flame beneath it is generous, the vigorous flow of steam through the trap should continue and be shown by a noisy and incessant collapse of bubbles in contact with the cold water.

Stir the water with the thermometer as the temperature rises, and when it is about 30 degrees warmer than it was at the start, pull the mouth of the trap quickly away from the calorimeter, stir the water quickly and *thoroughly*, take its temperature, and then weigh it carefully without loss of time.

The increase of weight since the previous weighing will, if all has gone well, show the weight of steam condensed.

From the data thus obtained the *latent heat of vaporization*, which is equal to the amount of heat given out in the *condensation* (not including the subsequent cooling) of 1 gm. of steam, is to be calculated.

NOTES.

The great difficulty of this Exercise — and it is a serious difficulty — is to find accurately the weight of steam condensed. This weight is not large, and an error of 1 gm. affects the result greatly.

If the trap is not used a considerable amount of *water* trickles into the calorimeter, condensation having occurred in the tube. When the trap is used a much more serious difficulty *may* be caused by an occasional sudden collapse of the steam in the trap, making a momentary partial vacuum there, into which water rushes from the calorimeter. This accident is likely to occur if the mouth of the trap is plunged too far beneath the surface of the water, and it is probably due to the cooling of the trap itself. It may be prevented by the use of a short rubber tube added to the exit-tube of the trap.

Evaporation from the calorimeter may cause perceptible error if the condensation and subsequent weighing take a long time.

The thermometer, if removed several times from the calorimeter, will have carried off enough water to affect the result.

Water may spatter from the calorimeter during the condensation if the vessel is too full or the tube dips too short a distance beneath the surface.

SOUND.

EXERCISE 47.

VELOCITY OF SOUND IN OPEN AIR.

Apparatus: A pendulum beating seconds. A small spy-glass. A board. A hammer or stone.

One experimenter strikes the board sharply just when the pendulum-bob passes the middle point of its arc. Another places himself at the start about 900 ft. distant from the first, in a line at right angles with the plane in which the pendulum swings, and then, looking through his glass, seeks to place himself at such a distance that the stroke made when the pendulum-bob passes through the middle point of its arc in one direction reaches his ear just when the bob passes through the middle point of its arc in the other direction. The distance which the sound travels in one second in one direction is thus roughly determined. As the wind may either help or hinder this movement, the conditions should afterward be reversed by having the experimenter with the glass strike the board, while the other stays at the pendulum and listens for the stroke, signalling to the striker to come nearer or go farther away until coincidence occurs as before. The mean of the two distances now found should be taken as the distance which sound would travel in one second in still air.

This method is not likely to give very accurate results. Its merit lies in its directness and simplicity. A still more direct and simple method is to place two persons a long distance apart, but in sight of each other, and have each in turn discharge a pistol or gun while the other notes, as well as he can, the number of seconds between the sight and the sound of the explosion.

EXERCISE 48.

WAVE-LENGTH OF SOUND.

Apparatus: Articles 94 and 95.

Push the piston-head along the tube until it is not more than 20 cm. from one end. Strike one prong of the tuning-fork upon a piece of soft wood and then hold it at this end of the tube. While the fork is sounding draw the piston-head gradually away from the fork, listening for the rise and subsequent fall of the sound, which occurs when the air-column attains and then exceeds the proper length. Find in this way, and mark, one effective position of the piston-face.

Find in like manner a second effective position of the piston-face, which will give a much longer air-column than before.

The distance between the two positions of the piston will be equal to one half of a wave-length.

EXERCISE 49.

NUMBER OF VIBRATIONS PER SECOND OF A TUNING-FORK.

Apparatus: Nos. 95 and 96.

The method of this Exercise is to draw the smoked glass along in a straight line beneath the style of the vibrating tuning-fork, thus tracing on the glass a sinuous curve, and simultaneously to cut this curve crosswise by means of traces made by the style of the pendulum.

Arrange the pendulum and fork so that the horizontal part of the pendulum motion shall be parallel to the motion of the fork-prongs, and so that the two styles may, when at rest, be in the same vertical plane, with their points as near each other as practicable (see Fig. 53).

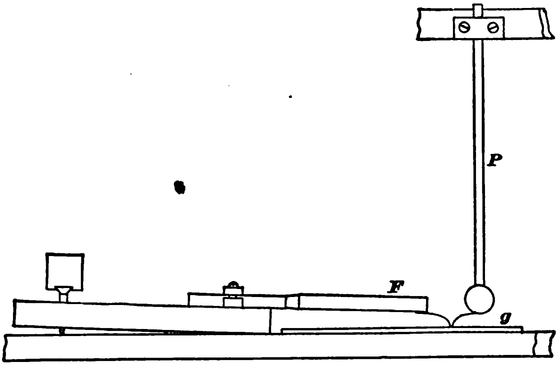

FIG. 53.

Place the piece of smoked glass under the tuning-fork and pendulum, and make such adjustments that the styles will bear lightly upon the glass. Set both pendulum and tuning-fork into vibration, and then draw the glass quickly along beneath them in a direction at right angles to the vibrations.

Count the number of vibrations of the pendulum per minute, and find from the smoked plate the number of vibrations of the tuning-fork corresponding to one vibration of the pendulum. Then calculate the number of complete (to and fro) vibrations of the tuning-fork per second.

ELECTRICITY AND MAGNETISM.

EXERCISE 50.*

LINES OF FORCE NEAR A BAR MAGNET.

Apparatus: A bar magnet (No. 97). A small compass (No. 98). A sheet of paper about 50 cm. square.

Fasten the sheet of paper on a table, and lay the magnet on the middle of the sheet, the north-seeking pole pointing north. Place the small compass at the extreme northeast corner of this magnet, and then move it away in the exact direction in which the compass-needle points. Continue this movement, changing direction in such a way as to follow continually the changing indication of the compass-needle, until the path reaches the edge of the paper, or returns to the magnet. Trace upon the paper the line thus followed by the middle of the compass, putting arrow-heads at several points to indicate the direction in which the north-seeking end of the compass-needle points at these places.

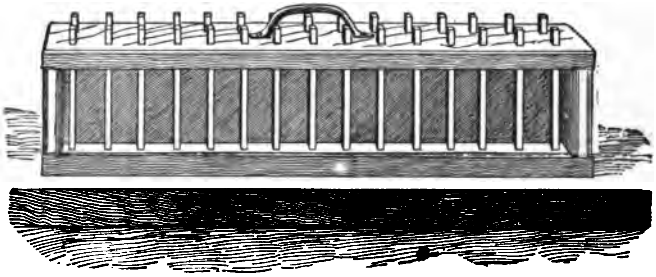

Fig. 54.

---

* Jarring magnets or touching like poles together may weaken the magnetism. When the magnets are not in use, it is well to keep them in a rack like that shown in Fig. 54, the north-seeking ends pointing downward.

Then place the compass a very little distance from the northeast corner of the large magnet toward the middle, and, starting anew, trace another line, and mark it as before.

Then beginning still farther toward the middle of the magnet, do as before.

Finally, start not more than 3 or 4 cm. from the middle of the magnet and trace a line.

Trace an equal number of lines on the western side of the magnet.

Trace upon the paper the outline of the magnet as used, marking the position of its north-seeking end. Trace also an arrow showing the direction *north*.

EXERCISE 51.

STUDY OF A SINGLE-FLUID GALVANIC CELL.

Apparatus: Materials for a small copper-zinc cell (without porous cup), using clean dilute sulphuric acid, about 20 parts in volume of water to one part in volume of concentrated acid.* A galvanoscope (Fig. 55). The zinc is at first unamalgamated.

(In this and every other Exercise in which galvanic cells are used, whenever wires have to be connected, by binding-screws, clamps, or mere twisting together, take care to make the connection firm, with good metallic contact.)

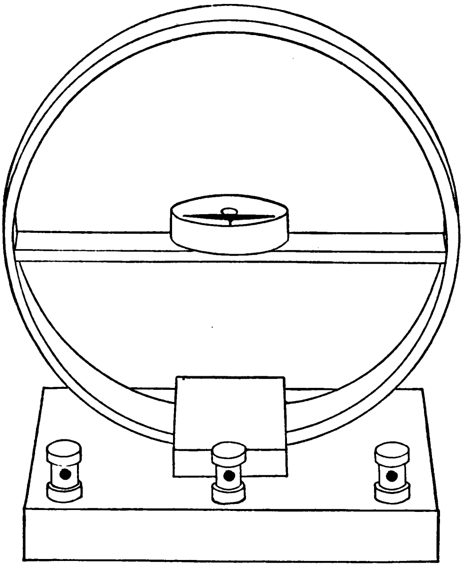

FIG. 55.

---

* In mixing *pour the acid slowly into the water*, stirring the mixture. Pouring water upon the acid is dangerous. A small quantity of acid sinking at once in a large mass of water is speedily cooled in spite of the strong chemical action. A small quantity of water floating on the top of a large mass of acid is heated to boiling, and then spatters the acid.

Place the galvanoscope so that each circle of wire upon it shall be in a vertical north and south plane.

Fill the glass with the dilute acid to a level about 1.5 cm. below the top.

Scour the strip of copper with emery-paper till so much of it as will be immersed in the acid is clean and bright.

Adjust the zinc strip and the copper strip in the clamps attached to the block at the top of the glass jar, so that each strip shall reach straight downward almost to the bottom of the jar.

ZINC UNAMALGAMATED; *Circuit Open.* — Observe for a short time and record what happens at the surface of each strip, all metallic connection between them being avoided.

Circuit Closed. — Then put the two strips into metallic connection with each other through the 15 turns of the galvanoscope, and again observe and record what happens at the surface of each strip. Note, too, the behavior of the galvanoscope-needle, and record the position in which it comes to rest, tapping the instrument lightly to prevent the needle from being detained by friction in a wrong position.

ZINC AMALGAMATED; *Circuit Open.* — Remove the zinc strip from the cell and *amalgamate* its surface by dipping it for an instant in mercury. Shake off or wipe off the superfluous mercury that clings to the strip and then replace the zinc in the cell. Take care that no mercury shall touch the copper.

Again observe and record the action at the surface of the zinc, the wires remaining unconnected.

Circuit Closed. — Again connect the strips through the 15 turns of the galvanoscope, read and record the positions of rest of the needle as soon as convenient, and read and record every minute thereafter for five minutes.

Observe what occurs at the metal surfaces.

If no decided change in the size of the deflection is noticed in the course of five minutes, take out the copper strip, which, *if the acid solution is in the right condition*, will still look bright, rinse it, and again scour it with emery-paper. Then replace it in the cell,* take a reading as soon as convenient, and continue reading for several minutes.

---

* It is better to use a fresh solution for this part of the Exercise; otherwise confusing results may follow.

EXERCISE 52.

STUDY OF A TWO-FLUID GALVANIC CELL.

Apparatus and Materials: The solid parts of a small Daniell cell, the zinc well amalgamated. Saturated solution of sulphate of copper, and a sulphuric acid solution of the same strength as that used in Exercise 51. A galvanoscope. The platform balance (No. 71).

Place the zinc in the porous cup and place this cup and the copper in the glass jar. Fill the jar with sulphate of copper solution to a level about 2 cm. from the top and fill the porous cup with the dilute acid to the same level, or a little higher. (See Fig. 56.)

Lift the copper plate from the solution, let it drip 15 seconds, then weigh it carefully with all the liquid that goes with it. Then replace it in the cell. Wipe the liquid from the pan of the balance.

Lift the zinc from the acid, let it drip 15 seconds, then weigh it carefully with all the liquid that goes with it. Replace the zinc in the cell and wipe the balance dry.

Connect the poles of the cell with the terminals of the 5-turn section of the galvanoscope, and note the time at which this is done. Read and record the position of the needle as soon as it comes to rest, tapping the galvanoscope lightly as in Exercise 51.

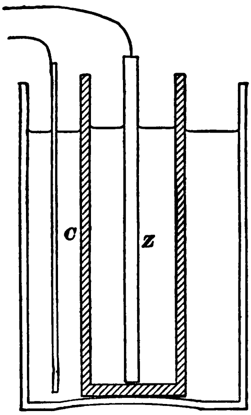

FIG. 56.

Read and record the position of the needle every five minutes thereafter for half an hour, if the length of the Exercise permits.

Break the circuit, noting the time; then weigh each of the metal plates, just as before, after allowing each to drip 15 seconds.

Find how much each plate has lost or gained in weight per *minute* of the time during which the circuit was closed.

NOTE. — Each plate carries about the same amount of liquid to the balance both times, so that the difference of its two weighings should tell, pretty nearly, its own change of weight. Wiping the plates might rub off some loose metal, and it is therefore not advisable. The zinc should not be freshly amalgamated at the beginning of this

Exercise; for freshly amalgamated zinc carries superfluous mercury, which would be likely to drop off during the Exercise, making the weighings of the zinc useless.

If the current increases in strength for several minutes after the circuit is closed, this is probably due to the gradual driving out of obstructing air from the pores of the clay cup. If the cell is to be put to any use requiring a very constant current, the porous cup, kept outside the jar, should be filled some little time before the work begins. When a film of moisture appears on the outside of the cup it may be placed in the jar.

EXERCISE 53.

LINES OF MAGNETIC FORCE ABOUT THE GALVANOSCOPE.

Apparatus: The galvanoscope with detachable compass. A Daniell cell. A commutator (Fig. 57). Short pieces of wire for making connections.

The lines of force to be examined in this Exercise are not due entirely to the current in the galvanoscope. They represent the combined action of the earth's magnetism and the current, and the character of the lines must depend, to some extent, upon the position of the galvanoscope with respect to the earth's lines of magnetic force. Something might be said in favor of studying the lines when the windings are placed north and south, as in the ordinary use of the instrument, but, on the whole, it seems better to place the windings east and west for this Exercise.

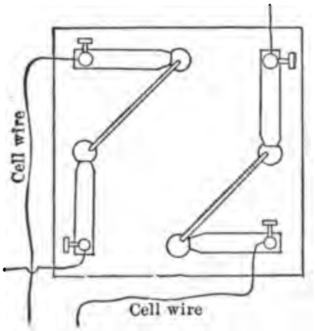

FIG. 57.

At some points the force due to the current will be in exactly the same direction as the horizontal force due to the earth. At such points the resultant force will be greater than that due to the earth alone, and the needle, if disturbed, will vibrate *more quickly* than it would if the current were not acting.

At other points the force due to the current is exactly opposite in direction to the horizontal magnetic force of the earth. At such points, if the force due to the current is greater than the other, the needle will be reversed and point south. If the earth's magnetic force prevails, the needle will still point north, but will vibrate *less quickly* than if the current were not acting.

In the diagram of the lines, points where the lines run north are to be marked "strong" or "weak," if the resultant force at these points is greater or less than the earth's horizontal magnetic force.

Put the Daniell cell in circuit through the commutator, with 15 turns of the galvanoscope, and place the latter so that the plane of its circle shall be east and west.

Make in the note-book two lines, E and W (Fig. 58), to represent half-size a horizontal cut through the middle of the galvanoscope.

FIG. 58.

Adjust the commutator so that the current will flow from east to west on the top of the galvanoscope circle.

Hold the compass about 15 cm. south of the centre of the circle on the same level, and record with an arrow-head on the diagram the direction of pointing of the needle. Move the compass north six stages of 5 cm. each, recording on the diagram the direction of the needle at each stopping-place.

Then place the compass inside the circle, near the eastern side, and mark the direction of the needle. Follow the needle, as in Exercise 59, and mark its direction at three or four other points several centimeters apart, until the line followed appears to be completed.

Make similar observations and record with respect to the western side of the circle.

Find, and record verbally, the direction of pointing just over and just under the top of the circle.

Reverse the current through the galvanoscope, by operating the commutator, and then repeat all the observations just indicated.

EXERCISE 54.*

RESISTANCE OF WIRES BY SUBSTITUTION: DIFFERENT LENGTHS.

Apparatus: A Daniell cell. A galvanoscope. A commutator. Five pieces of No. 30 German-silver wire, all of the same quality, one 200 cm. long, one 160 cm., one 120 cm., one 80 cm., one 40 cm., each suitably wound on a spool (see 103A). Two double binding-screws.

Put the zinc into the porous cup, and fill the latter with dilute acid to the usual level. *Let this cup stand outside the glass jar till a film of moisture appears upon its outside, showing that the liquid has filled its pores* (see *note* at the end of Exercise 52). Then finish putting the cell together in the usual way.

Place the galvanoscope, as usual, with the plane of its windings north and south, the needle pointing to the 0-pt. of the compass.

Connect the cell, the 15 turns of the galvanoscope, and the longest German-silver wire, in circuit, introducing the commutator in such a way that the current through the galvanoscope may be easily reversed (see Fig. 59).

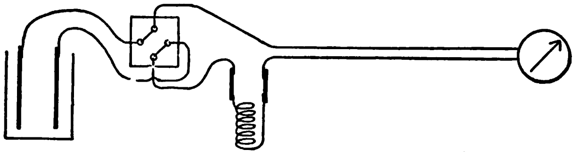

FIG. 59.

Read very carefully and record the position of the needle, tapping the instrument lightly, as usual; then, by means of the commutator, reverse the current through the galvanoscope, and again read and record.

Make similar arrangements and readings with each of the other pieces of German-silver wire in turn, proceeding from the longest to the shortest.

If time permits, after making observations with the shortest wire, use each of the others again in turn, ending with the longest.

---

* The present form of this Exercise and the next is due mainly to Mr. C. C. Hyde, at one time my laboratory assistant. — E. H. H.

Take the mean of all the deflections obtained with each wire as the true deflection with that wire.

On a piece of coördinate paper, ruled in very small squares, measure off horizontal distances, as in Fig. 60, to represent the various lengths of the wire, and above the points marked 40, 80, etc., place dots at vertical distances representing the deflections corresponding to the various wires. Then through these points draw a curve of such a character, *A* or *B*, as the facts require.

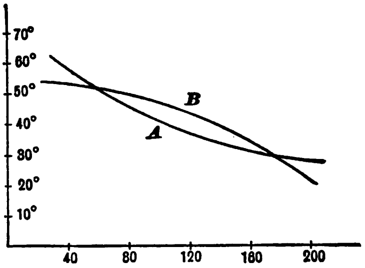

FIG. 60.

By measurement from any point on the base-line up to this curve one can now find what deflection would correspond to a wire of any given length between 40 cm. and 200 cm. This diagram will be of use in connection with the next Exercise.

NOTE.—Each porous cup used in this Exercise should be marked, so that the student who uses it may find and use the same cup in the next Exercise. The Daniell cells will probably differ mainly in the quality and thickness of their cups; and it is highly important to have the cell in the same condition, as near as may be, in Exercises 54 and 55.

EXERCISE 55.

RESISTANCE OF WIRES BY SUBSTITUTION: CROSS-SECTION AND MULTIPLE ARC.

Apparatus: The Daniell cell used in Exercise 54. A galvanoscope. A commutator. A spool with 200 cm. of No. 28 German-silver wire. Two spools with 200 cm. each of No. 30 German-silver wire. Two triple binding-screws (though double ones will serve, if the holes are large enough to take in two of the spool terminals side by side.) Screw calipers.

Set up the cell as in Exercise 54, and arrange the circuit as in Fig. 59, introducing the spool of No. 28 wire. Make careful observations, with the commutator in both positions, and take the mean of all the deflections.

Find by examination of the diagram of Exercise 54 what length of No. 30 German-silver wire would correspond to the same deflection, that is, would have the same resistance as the 200 cm. of No. 28 German-silver wire.

Measure carefully by means of the screw calipers the diameter of the No. 30 and of the No. 28 wire, and calculate the ratio of their areas of cross-sections. Compare this ratio with the ratio of equivalent lengths of these two wires.

Remove the No. 28 wire from the circuit, and put in its place the two spools of No. 30 wire joined in *parallel*, or *multiple*, as in Fig. 61, so that the current, as indicated by the arrowheads, will be divided equally between them. With this arrangement make observations as in the preceding case, taking finally the mean of the deflections recorded.

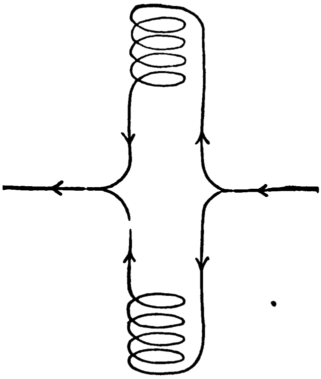

Fig. 61.

Find by examination of the diagram of Exercise 54 what length of No. 30 wire, single, corresponds in resistance, with the 200-cm. pieces of No. 30 wire, as now arranged.

EXPERIMENT.

(Preliminary to Exercise 56.)

Stretch a piece of No. 30 uncovered copper wire from *a* to *b* of No. 106 (Fig. 62), fastening it carefully beneath the washers under the lower nuts.

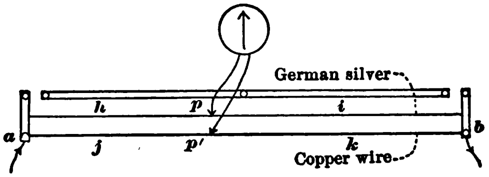

Fig. 62.

Connect with the astatic galvanometer (Fig. 63) two thin covered wires each about 1 m. long.

Send the current from a Daniell cell in at *a* and out at *b*. This current divides, a part going through the G.-s. wire, but the larger part through the parallel copper wire.

Hold one of the galvanometer-wires against any point of the G.-s. wire, at p for instance, and then touch the other galvanometer-wire to various points on the copper wire, until a point or contact p', is found that gives no current through the galvanometer, the contact at p being all the while maintained.

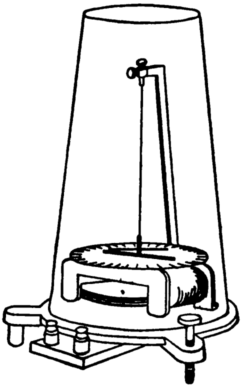

FIG. 63.

The two points p and p', between which no current flows when they are connected, are called a pair of *equipotential points* (§63). Let the parts into which p divides the G.-s. wire be called h and i, and the parts into which p' divides the copper wire be called j and k.

Experiment with various pairs of equipotential points (none of which should be very near the ends of the wires, because of certain imperfections of the apparatus at these ends) until it becomes clear that in every case

$$h : i :: j : k.$$

EXERCISE 56.

MEASUREMENT OF RESISTANCE WITH THE WHEATSTONE BRIDGE.

Apparatus: A Daniell cell. A Wheatstone bridge (No. 106). An astatic galvanometer (No. 107). The 20-m. copper coil (No. 103c). A box of resistance-coils (No. 108), with values given in ohms, or at least some known resistance of about 5 ohms. Screw-calipers.

Introduce the copper coil, the resistance of which is to be measured, as J, between the binding-posts d and e in Fig. 64. Introduce a known resistance as K, between the posts f and g, in the same figure. Connect one wire from the galvanometer to the binding-post m. Connect the other galvanometer-wire to the piece that makes sliding contact with the straight G.-s. wire, setting the contact at first at the middle point of this wire.

Attach one of the cell-wires to the binding-post a. *Touch* the other cell-wire for an instant to the post b, and note the effect upon the galvanometer. If the needle does not move, it is probable that the contact of the slider with the G. s. wire is not good. If the needle does move, observe the direction and magnitude of its motion.

Move the sliding contact to some new position, and again note the effect upon the galvanometer when the cell-wire touches *b* for an instant. Experiment in this way till some point *p* is found which gives no perceptible current when contact is made and continued for a second or two at *b*. (*Prolonged* contact at *b* will allow the copper coil to be heated by the current and suffer change of resistance.) It is best, after a little experimenting, to introduce such a resistance at *K* that the equilibrium point *p* will not be far from the middle of the wire.

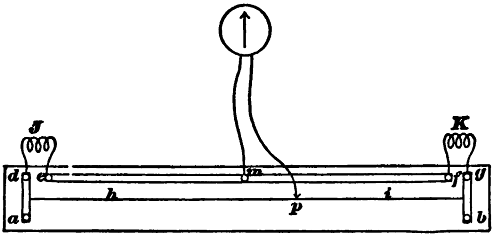

FIG. 64.

The distances *h* and *i* are now read. Observing that the resistances of the thick copper strips of the bridge are very small compared with *J* and *K*, we have

$$\frac{J}{K}=\frac{h}{i}, \quad \text{or} \quad J=K\times\frac{h}{i}.$$

The resistance of the copper wire is thus found in ohms. To find its specific resistance we must take account of its *length*, 20 m., and its diameter, which may be found by the screw-calipers.

EXERCISE 57.

CHANGE OF RESISTANCE WITH CHANGE OF TEMPERATURE.

Apparatus: A Daniell cell. A Wheatstone bridge. An astatic galvanometer. A known resistance of 1 or 2 ohms. A "temperature-coil" (No. 109). A vessel of ice-water. The boiler (No. 80) without top.

The unknown resistance *J* (see preceding Exercise) is now the "temperature-coil," which is attached to the Wheatstone bridge in the manner indicated by Fig. 65.

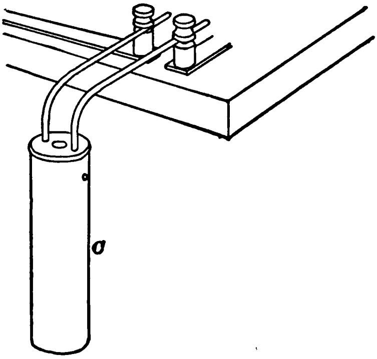

FIG. 65.

Measure carefully the resistance of this coil while it is in ice-water. Measure its resistance again with equal care while it is in the boiling water.

Calculate the temperature-coefficient of resistance.

EXERCISE 58.

BATTERY RESISTANCE.

Apparatus: Two similar Daniell cells. A galvanoscope. A commutator. A resistance-box.

Allow the pores of the cups to fill with liquid (see Exercise 54) before the cups are placed in the jars.

Variation of Effective Plate-area. — Put one of the cells in circuit, through the commutator, with a five-turn section of the galvanoscope.

Keeping the porous cup in contact with one side of the jar, and the copper and zinc as near together as may be (see Fig. 66), make and record the reading, then reverse the commutator and read and record again.

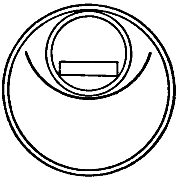

Fig. 66.

Without changing the distance between the copper and the zinc, raise both of them till they dip about 1 cm. only below the surface of the liquids. While they are in this position, read, reverse, and read again.

Variation of Distance between Plates. — Keeping the porous cup in contact with the side of the jar, put the plates as far apart as may be (see Fig. 67), and while they are in this position read, reverse, and read again.

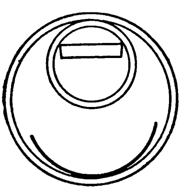

Fig. 67.

Cells in Parallel. — Join the two cells in parallel, zinc to zinc and copper to copper (see Fig. 68), and put them thus joined into the circuit, through the commutator and the resistance-box, with the 5-turn section of the galvanoscope.

Adjust the resistance-box so that none of its coils shall be in the circuit; read, reverse, and read again.

Introduce a resistance of 5 or more ohms, read, etc.

Cells in Series. — Join the two cells in series, other arrangements being as before.

Take readings with no coils of the box in circuit.

Take readings with the same coils in circuit that were used with the cells in parallel.

Under what conditions does the multiple, or parallel, arrangement of the cells give a stronger current than the series arrangement?

Under what conditions does the series arrangement give a stronger current than the multiple arrangement?

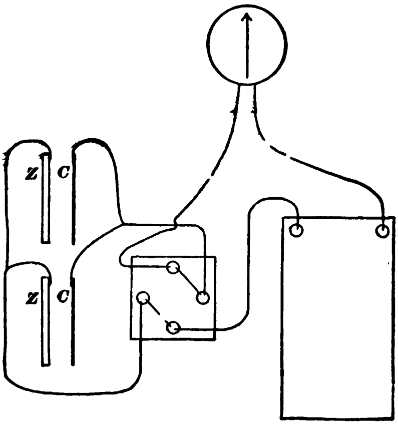

Fig. 68.

EXERCISE 59.

TELEGRAPHIC SOUNDER AND KEY.

Put together, "assemble," the parts of a very simple telegraphic key and sounder, the latter delicate enough to be operated by the current from a single Daniell cell.

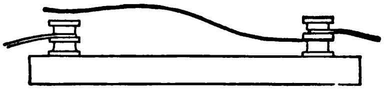

Fig. 69.

The key may be something like Fig. 69, where *b* is a strip of spring-brass, and the sounder may be correspondingly simple.

EXERCISE 60.

ELECTRIC MOTOR.

Put together, "assemble," the parts of a small electric motor, to be driven by a single Daniell cell.

EXERCISE 61.

THE DYNAMO.

Put together the parts of a dynamo which, driven by the motor of Exercise 60, will give a current capable of affecting, at least, the astatic galvanometer.

APPENDIX.

ALL THE ARTICLES IN THE FIRST LIST HERE GIVEN SHOULD BE FURNISHED TO EACH MEMBER OF THE LABORATORY SECTION.

LIST OF APPARATUS FOR THE EXERCISES OF THE FIRST PART.

No. 1. A 10-cm. section of a meter-rod.

No. 2. A meter-rod, marked on one side in feet and inches.

No. 3. A 30-cm. bevel-edged measuring-stick, marked on one side in inches.

No. 4. A waterproofed wooden cylinder about 8 cm. long and 4.5 cm. in diameter, loaded internally with shot so that it will float nearly submerged in water.

No. 5. A brass can about 14 cm. tall and 7 cm. in diameter, having a slightly declining, straight, overflow-tube, about 6 cm. long and 0.8 cm. in internal diameter, extending from a point about 1.5 cm., clear, below the top of the can (see Fig. 2). To prevent *dribbling* the junction of the tube and can should be covered, internally, with a coat of paraffin melted on.

No. 6. A brass catch-bucket with a wire handle, capable of holding about 175 gm. of water, and weighing not more than 50 gm.

No. 7. An 8-oz. spring-balance graduated to 0.5 oz. (There is now in the market an improved balance, graduated on one side in 10-gm. intervals and on the other side in 0.25-oz. intervals. It is, moreover, especially adapted for use in the horizontal position. This improved balance is desirable for this course.)

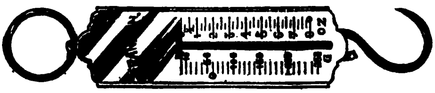

Fig. 70.

No. 8. A rectangular waterproofed block of wood, about 7 cm. long and 4.5 cm. square on the end, so loaded internally with shot that it will sink in water, but not enough to make it weigh more than 225 gm.

No. 9. A rectangular waterproofed cherry block about 7.5 cm. × 7.5 cm. × 3.8 cm. This block should be smooth, and therefore the waterproofing should be done by soaking it in *very hot* paraffin. For the best results this soaking should be done in a vacuum. Excess of paraffin should be scraped off before the block is used.

No. 10. A one-gallon glass jar of good quality. (It is poor economy to buy a poor jar and have it break with a liquid in it.)

No. 11. A lump of roll sulphur weighing about 175 or 200 gm. It is not worth while to cast these lumps into regular cylindrical form.

No. 12. A lead sinker with wire handle, weighing about 175 gm.

No. 13. A waterproofed wooden cylinder about 1 cm. in diameter and 20 cm. long. Doweling-rod, furnished by hardware dealers, serves well when waterproofed.

No. 14. A holder for keeping No. 13 upright in water. It consists of a waterproofed wooden rod about 12 cm. long and 1.3 cm. square on the end, provided with a clasp for attaching it to the side of a jar, and with two screw-eyes projecting from one side, the rings of which are large enough to let the cylinder No. 13 slip easily through them, but not large enough to allow the cylinder to tip far from the vertical position (see Fig. 2).

No. 15. A cylindrical glass jar, about 14 cm. tall and 10 cm. in diameter, with level top.

No. 16. A broad-mouthed bottle with ground-glass stopper, standing not much more than 11 cm. tall with stopper, and weighing, when filled with water, about 175 or 200 gm.

No. 17. A lever and supporting-bar. The lever is a 30 cm. section from a meter-rod, pivoted upon the smoothed cylindrical body of a brass screw which is driven horizontally into the end of a bar of hard wood about 25 cm. long, 5 cm. wide, and 3 cm. thick. A brass plate projecting from this bar and overhanging the middle of the lever prevents the lever from tipping far, while it allows sufficient freedom of motion. The lever itself, except for a distance of 2 cm. each side of the middle is cut away so that its top is level with the upper part of the hole through the centre. There should be a screw-hole running downward through the middle of the supporting-bar, to facilitate attaching it in the position shown by Fig. 7.

No. 18 (*A* and *B*). Two brass scale-pans about 6.5 cm. square, each with its suspending threads weighing accurately 1 oz. (that is, not differing from this weight by more than .01 oz.). Each pan is suspended by four strong linen threads meeting in a knot about 20 cm. above the pan, two of them continuing in a loop about 4 cm. long above this knot. (Fig. 7.)

No. 19. A set of iron weights, 8 oz., 4 oz., 2 oz., and two 1 oz., making a total of 16 oz. No weight should be in error more than .01 oz.

No. 20. A flat pine board about 50 cm. long and 15 cm. wide for use in the Exercises on Friction.

No. 21. A cubical block of wood about 3.7 cm. on each edge. A groove about 1 cm. wide and 2 cm. deep extends through the lower part of the block with the grain of the wood. An ordinary short screw extends through one side of the block into this groove, and serves to fix the block in position upon a meter-rod. *Across* the grain at the top of the block is a slot about 0.1 cm. wide and 0.5 cm. deep. (Figs. 8 and 28).

No. 22. Two bits of wood, each about 8 cm. long and 1 cm. square on the end. for supporting the spring-balance in a horizontal position. (Fig. 12.)

No. 23. A plate-glass mirror about 15 cm. long, 3.8 cm. wide, and 0.2 cm. thick, the coating on the back protected by paint or varnish.

No. 24. (*A* and *B*). Two straight-edged rulers of some wood that will keep its shape well — white pine, for instance — each about 30 cm. long, 5 cm. wide, and 1 cm. thick.

No. 25. A block like No. 21, but without the large slot and the screw. One side of this block is coated with white paper, and a vertical pencil mark is made across the middle of this paper. (Fig. 31.)

No. 26. A Walter Smith "school square," or other equally good protractor.

No. 27. A cylindrical mirror of nickel-plated brass, about 5 cm. tall and 8 cm. wide, cut from seamless tubing 4 inches in diameter and $\frac{1}{8}$ inch thick, mounted upon a semicircular base-board of wood of the proper radius of curvature. The base-board should be about 1.5 cm. thick.

No. 28. A piece of plate-glass about 7 cm. square and 0.6 cm. thick, for Exercise 20 on Index of Refraction. Two opposite edges, or narrow sides, of the glass should be ground tolerably plane and polished sufficiently to allow seeing readily through the whole width of the plate (see Fig. 24).

No. 29. A brass partition made to fit the small glass jar (No. 15) and to extend downward into the jar a distance equal to about one-third the diameter of the jar. It should be made of sheet brass about .07 cm. thick. The method of shaping and adjusting the partition is suggested by Fig. 71, where *A* shows a side view and *B* an end view of the partition. The flanges shown in *B* are bent more or less in adjusting the partition to fit the jar closely, but without too much pressure.

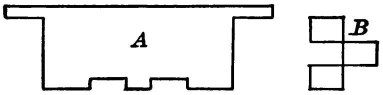

Fig. 71.

No. 30. An index of thin sheet brass made to clasp the side of the jar (No. 15). This index is a strip about 15 cm. long, before bending, and 1 cm. wide, tapered to a point at one end. To enable it to clasp the jar, about 3 cm. at the untapered end is bent over. (See *pb* in Fig. 26.)

No. 31. A circular (not elliptical) double-convex spectacle-lens, having a focal length not less than 12 cm. and not more than 16 cm. The lens is mounted on a block similar to No. 21. (See Fig. 28.)

No. 32. A white cardboard screen about 8 cm. square, of such thickness as to be held firmly in the narrow slot of the small block No. 21. (Fig. 28.)

No. 33. A small kerosene lamp of such size and shape as to fit it for the use shown in Fig. 29. The lower part of the chimney is surrounded by a thin sheet of asbestos paper, having a hole 3 or 4 mm. in diameter at the height of the flame.

No. 34. A wire, of the right size to fit into the narrow slot of No. 21, bent at a right angle, one arm about 6 cm. long, the other about 4 cm. (Fig. 31.)

LIST OF APPARATUS FOR THE EXERCISES OF THE SECOND PART.

Most of the articles in this list should be furnished to every student who is to perform all of the Exercises. But

No. 54 will serve for 6 members of the class.

Nos. 61, 62, 63	will	each	serve	for	3	members	of	the class.
Nos. 69, 70, 71, 72, 73	"	"	"	"	2	"	"	"
No. 74	"		"	"	4	"	"	"
Nos. 76, 77, 78	"	"	"	"	3	"	"	"
No. 79	"		"	"	4	"	"	"
Nos. 93, 94, 95, 96	"	"	"	"	2	"	"	"
No. 68	"		"	"	the school.			

No. 50. A 10-kgm. or 30-lb. straight spring-balance.

No. 51. A guard of wood or metal to bestride the bar of No. 50 and prevent the violent recoil in Exercise 26. (See Fig. 32.) The guard should be of such a length as not to allow more than 1 cm. of recoil; and therefore, if wires of very different strengths are used, a guard suitable for each should be supplied.

No. 52. A wooden cylinder about 2.5 cm. in diameter and about 3 cm. long, perforated and cut in such a way that it can be slipped on to the hook of the balance (No. 50), but will not turn around on the hook. (See Fig. 32.)

No. 53. A wooden cylinder to be conveniently fastened upright by means of a screw to the top of the table. (See Fig. 32.)

No. 54. Screw-calipers reading to 0.001 cm.

No. 55*a*. A rod of clear, straight-grained, white pine about 102 cm. long and 1.3 cm. square. Much care should be taken to make the width and thickness exact after the rods are thoroughly dried. (See Exercise 29.)

No. 55*b*. A rod twice as wide, but similar in all other respects to 55 A.

No. 56. A set of three hard-wood prisms, each about 3 cm. long and 2 cm. wide, the ends shaped as in Fig. 72. The height from base to apex on the end should be the same for all. These prisms are intended to support the rod and the index used in Exercises 28 and 29.

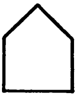
FIG. 72.

No. 57. A strip of wood about 32 cm. long, 0.5 cm. wide, and 0.2 mm. thick, to serve as an index in Exercises 28 and 29.

No. 58. A 10-cm. scale divided to mm., attached to a base-block so as to stand upright, for use in Exercises 28 and 29.

No. 59. A metal pan about 12 cm. in width, with looped strings attached, to carry the weights used in Exercises 28 and 29.

No. 60. Set of iron weights, 100, 200, 300, 500, 1000 gm., for use in Exercises 28 and 29. Corresponding weights marked in ounces (see No. 19) may be used in place of gram-weights.

No. 61. A rod of clear, straight-grained, ash 1 m. long and 1 cm. square in cross-section, one end of which is fitted firmly into the middle of a cross-bar about 32 cm. long, 1 cm. thick, and 3 cm. wide (at the middle). Near each end of the cross-bar is a peg to take the loop of a string, the pegs being 30 cm. apart. Projecting through the cross-bar, in line with the axis of the rod, is a round nail or brad 2 cm. long. (In place of the cross-bar a circle of wood may be used, as in Fig. 35).

A cleat about 4 cm. long and 2 cm. square, having on one side a notch 1 cm. wide and 0.5 cm. deep, goes with the rod for attaching it to the horizontal bar above the table-top. Cleat not shown in Fig. 35.

No. 62. A rod like No. 61, but 2 cm. square in cross-section and provided with a correspondingly heavy cross-bar and cleat.

No. 63. A sheet of cardboard or metal upon which is traced one-eighth part of the circumference of a circle, of diameter about equal to the length of the cross-bar of No. 61, the arc being divided into degrees and half-degrees. This is for use in the twisting experiments with Nos. 61 and 62.

No. 64. Two small tumblers. (See Fig. 36.)

No. 65. Tubes and pinch-cock for the Exercise on Balancing Columns. (See Fig. 36.)

No. 66. Wooden support for No. 65, with meter-rod. (See Fig. 36.)

No. 67. Glass tube for Boyle's law (see Fig. 37), about 0.7 cm. in diameter inside; the closed arm about 30 cm., the other about 110 cm. long. The short arm of this tube should be of very uniform bore.

No. 68. An inexpensive barometer, the readings of which should not differ more than 0.3 cm. from those of a standard instrument. (See Exercise 33.)

No. 69. A 2-litre glass bottle, provided with a perforated rubber stopper through which extends a short piece of glass tubing connected with a thick, soft, rubber tube about 15 cm. long, carrying a strong pinch-cock. (This piece of apparatus is for Exercise 24 on the Density of Air (see Fig. 38). The bottle and the tubing must be strong enough to be in no danger of collapsing when all the air is removed from it. Red antimony-rubber is recommended for the stopper and tube, as it is very pliable.)

No. 70. Glass U-tube, each arm of which is about 1 m. long and 0.5 cm. in diameter inside. For pressure-gauge in Exercise 34. (See Fig. 38.)

No. 71. Platform-balance weighing from 1 kgm. to 0.1 gm., provided with a set of brass weights.

No. 72. Air-pump for both exhaustion and compression, with simple base for attachment to floor or wall. The capacity should not be less than 100 cu. cm. per stroke. (See Fig. 38.)

No. 73. A metal Y-tube with attached rubber tubes, for connecting Nos. 69, 70, and 72, as in Fig. 38.

No. 74. A smooth flat board, protected from warping by cross-pieces at the ends, upon which a square 30 cm. on the side is laid off and divided into squares each 5 cm. on the side, the lines being made with a pencil or a knife, a hole about 0.3 cm. in diameter being drilled nearly through the board at every crossing (see Fig. 73); the under side of the board, if it is of soft wood, is covered with a thick, smooth, sheet of tin. Several iron pegs fitting well the holes in the board. Three smooth round marbles equal in size, or, better, three steel bicycle-balls to support the board in a horizontal position and give it freedom of motion.

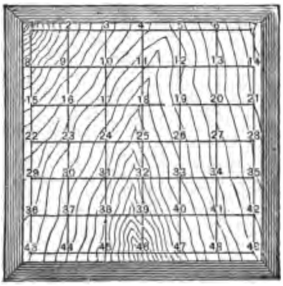

FIG. 73.

For certain uses the board should be provided with a bar, marked off in centimeters and millimeters, extending across its top and raised a few millimeters from the surface.

It is quite as well to make the board in 2-inch squares as in in 5-cm. squares.

No. 75. A bed for No. 50, to hold the balance flat on its back and to raise the horizontal string leading from the book a very little above the surface of the board No. 74, when this is resting upon the supporting balls. (See Fig. 74.)

No. 76. Two strong brass carriages (see Fig. 75), each large enough to hold about 1 kgm. of iron, and sufficiently well made to continue in motion after being gently started down an incline of 1 in 50. To each carriage is attached a small, thin, rubber tube about 50 cm. long and of such quality that it will bear stretching to twice its original length. For use in Exercise 36.

No. 77. Two smooth straight planks, each about 120 cm. long and 15 cm. wide, to serve as tracks for No. 76 (see Fig. 40). Each plank should have at one end an elevating-screw capable of raising that end 2 cm. higher than the other; and along all four edges of one side cleats rising about 1.5 cm. above the surface. The clear space between the side cleats should be as much as 11 cm. wide.

No. 78. Cast-iron weight or weights amounting to about 1 kgm., of such dimensions as to be carried securely in one of the carriages No. 76.

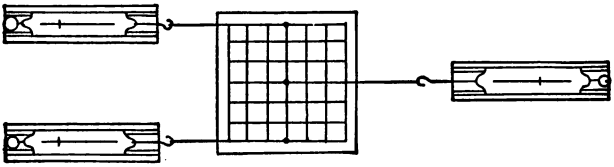

FIG. 74.

No. 79. The whole apparatus used for Exercises 37 and 38 on Action and Reaction, as follows:

Two ivory balls, one of about 50 gm., the other three or four times as heavy, each provided with a hook for suspension.

A board about 20 cm. long, 6 cm. wide, and 1 cm. thick, bevelled along one edge (from which the pendulum-balls are to hang), having three fine slots in the acute edge of the bevel, No. 1 near one end, No. 2 separated from No. 1 by a distance equal to the sum of the radii of the balls, No. 3 about 0.3 cm. farther from No. 1. (See Fig. 42.)

Several yards of small, uncovered, copper wire, strong enough to bear twice the weight of the large ball. In use the wires are attached to the pegs or tacks in the supporting board and hang down through the notches, Nos. 1 and 3 when putty is in use (Fig. 45), Nos. 1 and 2 at other times.

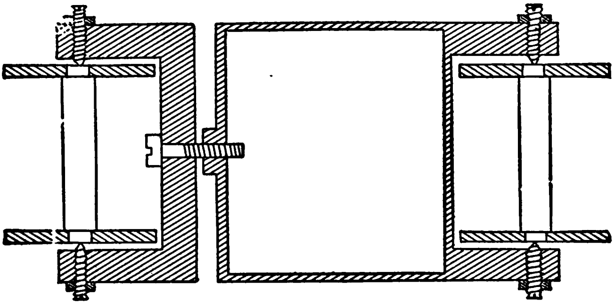

FIG. 75.

A base-board 1 m. long with graduated raised bar along its top, carrying two detents for holding the balls in place before release. (See Fig. 44.) The detents should be attached at any part of the bar, and the line of sight through the slots of the two uprights (see Fig. 34) should be parallel to the bar. (The base-board here described is long enough, if the suspension is not longer than 2 m.

If the suspension is much longer than this, which is desirable, two base-boards can be used.

No. 80. A cylindrical sheet-copper vessel about 15 cm. tall and 10 cm. in diameter, supported on three legs, which are kept from spreading by a circular plate of sheet copper, or a ring, connecting them all at the bottom. These legs should raise the vessel about 20 cm. from the table upon which they stand. This vessel is to be used as a boiler, and has, leading out 2 cm. from the top, a side tube from which the steam may be carried off when the top of the vessel is closed. A conical tube of sheet-copper about 30 cm. tall is made to fit the top of the cylindrical vessel internally, as the cover of a pail fits. It must fit well, for the junction should be, as nearly as practicable, steam-tight. The top of the cylinder should not therefore be wired, but should be left flexible. The open top of the conical tube is about 2.5 cm. in diameter and of such a shape as to be readily closed by a cork stopper. A side tube leaks out from the cone about 2 cm. from the top. Through this tube, the other apertures being closed, steam escapes when the apparatus is used in testing the boiling-point of a thermometer.

A small mercury-gauge accompanies this vessel and may be attached to the lower outlet in testing the effect of pressure upon boiling temperature in Exercise 39. (See Fig. 46.)

No. 81. A sheet-copper dipper about 10 cm. deep and 4 cm. wide encircled, about 2 cm. from the top, by a flat flange of sheet-copper about 4 cm. wide. See Exercise 43 (Fig. 51).

No. 82. An inexpensive paper-scale centigrade thermometer graduated a few degrees below 0° and above 100° C.

No. 83. A Bunsen burner.

No. 84. A rod or tube of brass about 5 mm. in diameter and about 60 cm. long, to one end of which a very short tip of pointed steel wire is soldered. For use in Exercise 40.

No. 85. A tube of sheet-iron, tinned or "galvanized," open and slightly flared at both ends; about 2.5 cm. in diameter and a few mm. shorter than No. 84, which is to be heated within it by the action of steam. (See Fig. 47.)

The ends are provided with very short cork stoppers, *flush* with the ends of the tube, which are perforated so that the brass rod (No. 84), when placed within the tube, extends slightly through the stopper at each end.

No. 86. A wooden rack for holding No. 85 in position when in use. (See Figs. 47 and 49.)

No. 87. A glass tube containing dry air retained by a column of mercury, for use in Exercises 41 and 42.

Take a glass tube 50 cm. long, about 0.5 cm. outside and about 0.15 cm. inside, in which a column of mercury about 10 cm. long does not vary more than 1% of its length when measured in different positions. Attach to this tube another, of similar dimensions but not necessarily regular in size of bore, by means of a short thick-walled piece of antimony-rubber tubing. Heat the calibrated tube, about 3 cm. from the free end, with a small flame, and draw out the tube at this point till it is so small that it can be readily melted off when the proper time comes.

To fill this tube with dry air follow the indications of Fig. 76, placing the tube to be filled inside a sheet-iron heating-tube similar to but shorter than

No. 85, the narrowed part *n* being just outside the heater. Steam is sent through the heating-tube, and at the same time an air-pump connected with *o* draws air in at *i*, through the drying-bottle containing strong sulphuric acid and glass beads, through the heated glass tube, and out through the mercury in the bottle at the other end. After five minutes of this operation it may be assumed that the glass tube is dry. The current of air is then stopped and the tube is melted off and sealed at *n*. The pump is then worked again to draw out a part of the air in the tube, so that mercury may take its place. The degree of exhaustion attained is indicated by the gauge connected at *g*. When enough air has been drawn out, disconnect the pump and let full atmospheric pressure act upon the mercury in the bottle, forcing it up into the tube. The confined dry-air column in the tube should finally reach about two-thirds of the way from the sealed end to the rubber joint, when both arms of the tube are horizontal at ordinary temperature and pressure.

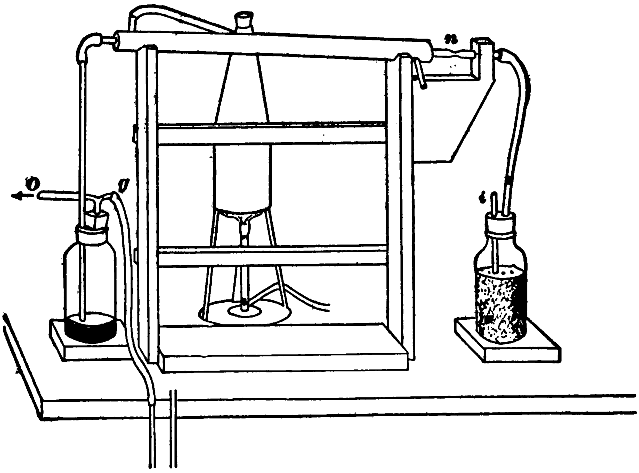

FIG. 76.

No. 88. A "galvanized iron" tray about 60 cm. long, 15 cm. wide and 5 cm. deep, having a tubulure at one end. This tray is to hold ice-water or snow for cooling the air-column, the tube containing which is thrust through a cork in the tubulure. If the tray has two tubulures at each end, it can be used to cool four air-tubes at once. (See Fig. 50.)

No. 89. A calorimeter of about 600 cu. cm. capacity. The thin nickel-plated brass vessels, larger at top than at bottom, sold at hardware stores as "liquor-shakers," serve exceedingly well for this purpose.

No. 90. Half a kilogram of lead shot.

No. 91. A strong canvas bag 30 cm. long and 20 cm. wide, for pounding ice.

No. 92. A glass trap for catching the water formed by condensation in the conducting-tube in Exercise 46. (See Fig. 52.)

No. 93. A small spy-glass.

No. 94. Glass tube about 2.5 cm. in diameter and about 1.2 m. long, provided with a piston consisting of a cork stopper and a rod of wood or metal. For use in Exercise 48.

No. 95. Tuning-fork of about 256 double vibrations per second.

No. 96. Apparatus for determining the number of vibrations per second of No. 95, by means of a tracing on smoked glass. (See Fig. 53.) The pendulum should make three or four single beats a second.

No, 97. A straight bar magnet about 15 cm. long and 1 cm. square in cross-section. For Exercise 50.

No. 98. A small magnet compass with needle 2 or 3 cm. long.

No. 99. A small copper-zinc cell for one fluid, consisting of a small glass jar, or tumbler, and two thin strips, one of zinc and one of copper, each about 10 cm. long and 1 cm. wide, each provided with a copper wire, about No. 22, some 30 cm. long. A block of wood about 3 cm. wide, fitted to the top of the jar, carries two spring clamps for holding the metal strips.

No. 100. A galvanoscope, with coil about 15 cm. in diameter, wound with 15 turns of wire, about No. 20, in such a way that 5, 10, or 15 turns may be used at will. This instrument is not to be treated as a tangent galvanometer, and the compass upon it is small. (See Fig. 55.)

No. 101. The solid parts of a small Daniell cell, the copper and zinc plates provided with wires, about No. 20, some 30 cm. long.

No. 102. A simple commutator for electric currents. (See Fig. 57.)

No. 103*a*. Six wooden spools (Fig. 77, *half size*) each wound with uncovered No. 30 German-silver wire, two of them carrying 200 cm. each, one carrying 160 cm., one 120 cm., one 80 cm., one 40 cm.

No. 103*b*. A similar spool with 200 cm. of No. 28 German-silver wire.

No. 103*c*. A similar spool with 2000 cm. of No. 30 covered copper wire.

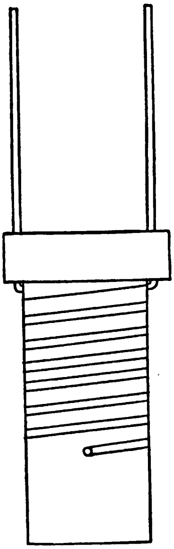

Fig. 77.

(All of the G.-s. wires of Nos. 103*a* and 103*b* should be of the same quality, all of the No. 30 being, if possible, from the same piece.)

Every spool should be *soaked* in melted paraffin before the wire is laid on it. Every wire should be wound in such a way as to have no magnetic effect. Every spool should be *dipped*, not soaked, in melted paraffin after it is wound.

At some point on each spool the wire should be left so exposed that its diameter can be measured by means of screw calipers. For this purpose a bit may be left projecting beyond the point of soldering to the heavy copper terminals. (I am indebted to Mr. C. C. Hyde, at one time my laboratory assistant, for the replacement of a cumbrous "resistance-rack" by these coils. — E. H. H.)

No. 104. A pair of double binding-posts for use with the spools of No. 103.

No. 105. A pair of triple binding-posts for introducing two of the spools of No. 103*a* into the circuit in parallel. (Not *necessary*.)

No. 106. A simple form of Wheatstone's bridge, shown in Fig. 64, with thick connecting strips of brass or copper of very small resistance in comparison with the thin German-silver wire, *hi*, one meter long, which is stretched along a meter-rod (not shown), and is neatly soldered to the strips at each end. At *a*, *b*, *d*, *e*, *f*, *g*, and *m* are binding-posts. The post *a* has two nuts, and under the lower nut is a washer, the edge of which comes just over the inner edge of the metal strip beneath. The post *b* is similarly provided. This makes it possible to stretch a thin wire from *a* to *b* and fasten it securely beneath the washers, so that just one meter of its length will be exposed, as in Fig. 62. Battery connections can be made at *a* and *b* without disturbing this wire, which is, however, not kept in place during the ordinary use of the apparatus. The gaps *de* and *fg* should be of such a width as to receive conveniently the terminals of the resistance-coils of No. 103.

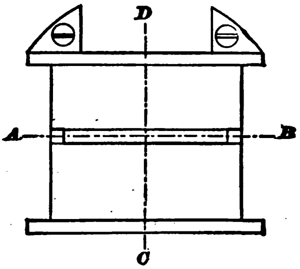

FIG. 78.

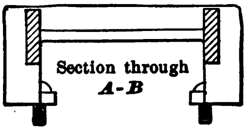

FIG. 79.

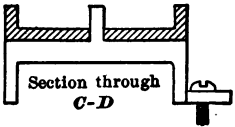

FIG. 80.

A suitable slide is provided for making contact with the wire *hi*.

No. 107. An inexpensive astatic galvanometer, that shown in Fig. 63, for instance. The small cost of this form is partly due to the fact, that the metal frame on which the wire is wound is in such shape that it can be cast. Fig. 78 shows a top view of this frame before winding. Figs. 79 and 80 show sections. All these figures are one-half size.

No. 108. A resistance-box with a range from 1 ohm to 10 ohms or higher.

No. 109. A temperature-coil, for showing change of resistance with change of temperature (see Fig. 81). This consists of fine copper wire, uncovered, wound in grooves in a hollow hard-rubber cylinder. The terminals are convenient for inserting the coil in one of the gaps of the Wheatstone bridge (No. 106). (See Fig. 65.)

In use the coil, so far as the windings extend, is immersed in water. A hole in the plug at the top of the cylinder gives admission to a thermometer.

No. 110. The parts of a telegraphic sounder and key, the simpler the better, to meet the requirements of Exercise 59.

No. 111. The parts of a small electric motor, to meet the requirements of Exercise 60.

No. 112. The parts of a small dynamo, to meet the requirements of Exercise 61.

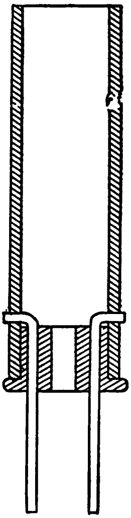

FIG. 81.

LABORATORY TABLES.

The laboratory tables used in the Cambridge grammar-schools are well suited to the work of this course. They are about 10 ft. long, 4 ft. wide, and 2 ft. 10 in. tall. They have white-pine tops about 1½ in. thick, and heavy white-wood legs. Extending from end to end over each table are two horizontal bars, about 2 in. by 3 in., adjustable at various heights (which should range from 1½ ft. to 3½ ft. by 3-in. intervals) above the table-top, their ends, which are cut in tenons, sliding in grooves in the supporting posts. These posts are fastened to the frame of the table and rise through slots in the table-top, being *flush* with the ends of this top and about 10 in. distant from the sides. Pins of iron or wood placed in holes in these posts support the ends of the horizontal bars. To adapt these tables to Exercises 29 and 30 (Second Part of book), holes about 1½ in. in diameter should be bored through the top.

For Exercises in Heat this table should have a gas-pipe running along the middle of the top, with stop-cocks running left and right. This pipe should be readily detachable.

One table will accommodate six pupils.

A FINE IS INCURRED IF THIS BOOK IS NOT RETURNED TO THE LIBRARY ON OR BEFORE THE LAST DATE STAMPED BELOW.

CANCELLED

WIDENER
APR 05 2001
CANCELLED

JAN 28 '76 H